Boiling Water Reactor Emergency Core Cooling System Evaluation Model

Code Sensitivity for SVEA-96 Fuel

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CENPD-283-NP-A

Boiling Water Reactor Emergency Core Cooling System Evaluation Model:

Code Sensitivity for SVEA-96 Fuel

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CENPD-283-NP-A

Boiling Water Reactor Emergency Core Cooling System Evaluation Model:

Code Sensitivity for SVEA-96 Fuel

July 1996

ABB Combustion Engineering Nuclear Operations

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CENPD-283-NP-A REPORT

Part I

NRC Acceptance Letter, Safety Evaluation Report (SER), and Technical Evaluation Report (TER)

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

October 25, 1995

Derek Ebeling-Koning, Manager
Licensing and Safety Analysis BWR Fuel Operations
Combustion Engineering, Inc.
1000 Prospect Hill Road
Windsor, Connecticut 06095-0500

SUBJECT: CENPD-283-P, "Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Sensitivity for SVEA-95 Fuel" and Related Documents (TAC M86126)

Dear Dr. Eberling-Koning:

Combustion Engineering, Inc., (CE) submitted the subject report CENPD-283-P by letter dated March 3, 1993. Related documents were submitted by letters dated July 7, 1995, and August 9, 1995. The staff has completed its review of the subject topical report and the related documents. The staff finds the report and related documents to be acceptable to the extent specified and under the limitations delineated in the NRC evaluation.

The staff does not intend to repeat the review of the matters that are described in the report and that were found acceptable when the report appears as a reference in license applications, except to ensure that the material presented is applicable to the specific plant involved. The staff's acceptance applies only to the matters described in the report.

In accordance with procedures established in NUREG-0390, it is requested that CE publish an accepted version of this report within 3 months of receipt of this letter. The accepted version shall incorporate this letter and the enclosed evaluation after the title page. The accepted version shall include an -A (designating accepted) following the report identification symbol.

Should the staff's criteria or regulations change so that its conclusions as to the acceptability of the report are invalidated, Combustion Engineering and/or applicants referencing the topical reports will be expected to revise and resubmit their respective documentation, or submit justification for the continued effective applicability of the topical reports without revision of their respective documentation.

Sincerely,

Robert C. Jones

Robert C. Jones, Chief
Reactor Systems Branch
Division of Systems Safety and Analysis
Office of Nuclear Reactor Regulation

Enclosures:
As stated

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

ATTACHMENT 1

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION RELATING TO TOPICAL REPORT CENPD-283-P "BOILING WATER REACTOR EMERGENCY CORE COOLING SYSTEM EVALUATION MODEL: CODE SENSITIVITY FOR SVEA-96 FUEL"

1.0 INTRODUCTION

By letter dated March 3, 1993, Combustion Engineering, Inc., (CE) submitted Topical Report CENPD-283-P, "Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Sensitivity For SVEA-96 Fuel," extending the application of the ABB ECCS LOCA evaluation model methodology to the SVEA-96 fuel design. This report was supplemented with a submittal dated July 7, 1995, CENPD-283-P-RAI, "Boiling Water Reactor ECCS Evaluation Model: Response to Request for Additional Information on Code Sensitivity for SVEA-96 Fuel." Revision 1 to this report (CENPD-283-P-RAI, Rev.1) was submitted on August 9, 1995. The original ABB ECCS methods and supporting sensitivity studies (Reference 1) have been previously submitted, reviewed, and approved by the staff (Reference 2). This safety evaluation (SE) addresses the staff review of the extension of the above approved methodology and sensitivity studies to the SVEA-96 fuel design.

2.0 SUMMARY

The staff performed its review of the code sensitivity for SVEA-96 fuel reported in CENPD-283-P under a technical assistance contract with International Technical Services, Inc., (ITS). The evaluation and findings are described in the attached ITS technical evaluation report (TER) which becomes a part of this SE.

The original methodology was approved for use with the QUAD+/SVEA-64 fuel designs with restrictions. Specifically CE was required to provide NRC with a plant-specific reload analysis report for review covering plant and fuel specific items, such as the use of NRC approved models and justification of experimental data to verify the convective spray heat transfer coefficients to ensure compliance with 10 CFR 50.46, Appendix K. The items reviewed for extending the original ABB ECCS methods to the SVEA-96 fuel include the following: (i) the adequacy of the nodalization selected for the SVEA-96 fuel design; (ii) conformity of input changes to the acceptance criteria of 10 CFR 50.46; (iii) adequacy of the spray convective heat transfer coefficients selected for the SVEA-96 fuel; (iv) adequacy of model option and input changes due to SVEA-96 fuel; and (v) impact of mixed cores on the BWR LOCA transient. The computer codes (i.e., internal models) used for this LOCA methodology remain unchanged from those that were previously documented.

The attached TER summarizes the review findings regarding ABB/CE's demonstration of the adequacy of the sensitivity studies performed by ABB/CE in support of its evaluation model using the ABB\CE system of computer codes for BWRs with SVEA-96 fuel.

3.0 EVALUATION

CE provided additional information to supplement the information contained in CENPD-283-P in a submittal (CENPD-283-P-RAI) dated July 7, 1995, and in a submittal (CENPD-283-P-RAI, Rev.1) dated August 9, 1995. This was in response to a request for additional information (RAI) prepared by the staff and its contractor (Reference 3). The contractor evaluation and findings are described in the ITS technical evaluation report (TER) which is enclosed as a part of this SE. As described in the TER certain items must be addressed and properly utilized as described in the topical report and its supplements to provide an acceptable ECCS LOCA analysis licensing basis for the SVEA-96 BWR fuel. In general the vendor adequately demonstrated the conservative nature of its modified ECCS methodology for SVEA-96 fuel using previously approved codes, subject to the limitations set forth below:

1. The review did not include evaluation of the adequacy of the implementation of the XL-S96 CPR correlation, since the vendor chose to address this issue in report CENPD-293.

2. This methodology documented in CENPD-283-P is approved for extension to the SVEA-96 fuel only. Previous approvals remain unchanged and this methodology cannot be extended to other fuel and plant designs without NRC approval.

3. Since the convective spray heat transfer coefficients selected for the SVEA-96 fuel design were selected by procedure to show conservatism, but not supported by experimental data, this procedure should not be extended to other fuels without experimental verification.

4. Similarly, the coefficients in the CCFL option that were shown to be insensitive to these coefficients for the SVEA-96 fuel should not be extended to other fuels without being validated by experimental data.

5. It is expected that the insensitivity demonstrated by the selected CCFL and convective heat transfer coefficients to the predicted system parameters would be plant design independent; however, the vendor will be required to demonstrate the acceptability of both of these in any instance when the calculated PCT approaches the Appendix K limit. The vendor submitted PCT data by facsimiles dated September 19, 1995, and September 27, 1995, that showed the CCFL correlation has a 100 °F sensitivity in the temperature range of the Appendix K limit (1800 °F to 2200 °F). The data showed that as the peak linear heat generation rate approaches 36 kw/m the PCT goes above the Appendix K limit. Therefore, the vendor must include a conservative bias. By a faxcimile dated October 16, 1995, the vendor stated that when the PCT is greater than 2100 °F, the CCFL correlation shall include a conservative bias that bounds the scatter in the data base. The bias introduced to the base CCFL correlation will be such that conservative bounding predictions are obtained from the data base of all fuel assembly components that were used to derive the basic CCFL correlation.

6. The overall acceptability of the vendor's ECCS methodology for the BWR remains subject to the restrictions and limitations of all other governing SEs of relevant computer codes, models, and fuel designs and their previous approvals.

4.0 REFERENCES

1. ABB letter ATOF-91-261 from D. B. Ebeling-Koning to R. C. Jones Jr. (NRC), Transmittal of Approved Licensing Topical Reports RPB 90-93-P-A (WCAP-11284) and RPB 90-94-P-A (WCAP-11427), December 18, 1991.
2. NRC letter from A. Thadani to W. J. Johnson, Westinghouse Electric Corporation, August 22, 1989.
3. R. Frahm (NRC) to D. Ebeling-Koning (ABB), "Request for Additional Information on CENPD-283-P," March 28, 1995.
4. ITS letter dated September xx, 1995 to R. Frahm (NRC) with attached TER on the review of the ECCS model sensitivity for the SVEA-96 fuel.

ITS/NRC/95-1

TECHNICAL EVALUATION:
BOILING WATER REACTOR EMERGENCY CORE COOLING SYSTEM EVALUATION MODEL:
CODE SENSITIVITY FOR SVEA-96 FUEL
CENPD-283-P
FOR
ABB COMBUSTION ENGINEERING NUCLEAR OPERATIONS

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Prepared for
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TECHNICAL EVALUATION OF BOILING WATER REACTOR EMERGENCY CORE COOLING SYSTEM EVALUATION MODEL: CODE SENSITIVITY FOR SVEA-96 FUEL CENPD-283-P ABB COMBUSTION ENGINEERING NUCLEAR FUEL

1.0 INTRODUCTION

In the topical report, CENPD-283-P entitled "Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Sensitivity for SVEA-96 Fuel," (Ref. 1), ABB Combustion Engineering Nuclear Fuel (ABB/CE) submitted a description of the impact of extending its previously NRC approved emergency core cooling system (ECCS) evaluation model methodology (Ref. 2) to SVEA-96 fuel. Additional information was provided in Reference 3.

The original methodology, based upon use of the GOBLIN/DRAGON/CHACHA-3C computer codes (Refs. 2 and 4), was approved for use with QUAD+/SVEA-64 fuel designs with restrictions (Ref. 2). Specifically, ABB/CE was required to provide NRC with a plant-specific reload analysis report for review covering plant and fuel specific items, such as the use of NRC approved models and justification of experimental data used to verify the convective spray heat transfer coefficients to ensure compliance with 10CFR 50.46 Appendix K.

In the subject topical report ABB/CE presented materials to demonstrate: (i) the adequacy of the nodalization selected for the SVEA-96 fuel design; (ii) conformity of input changes to the acceptance criteria of 10 CFR 50.46; (iii) adequacy of the spray convective heat transfer coefficients selected for SVEA-96; (iv) adequacy of model option and input changes due to SVEA-96 fuel; and (v) impact of mixed cores on BWR LOCA transient. The computer codes (i.e., internal models) utilized for this LOCA methodology remain unchanged from those documented in Reference 2. No plant specific data or analysis was presented.

This technical evaluation report summarizes review findings regarding ABB/CE's demonstration of the adequacy of the sensitivity studies performed by ABB/CE in support of its ECCS Evaluation Model using the GOBLIN system of computer codes for BWRs with SVEA-96 fuel.

2.0 SUMMARY

ABB/CE presented results of LOCA sensitivity studies to demonstrate adequacy of its licensing type applications of its ECCS methodology to the SVEA-96 fuel design. For that purpose, ABB/CE briefly described its previously approved ECCS methodology and its associated GOBLIN/DRAGON/CHACHA-3C computer codes and design differences of SVEA-64 and SVEA-96 fuel designs. In addition ABB documented changes in models and input necessitated by the application to a new fuel design, SVEA-96.

2.1 GOBLIN/DRAGON/CHACHA-3C Computer Codes

The GOBLIN code is used to compute the thermal-hydraulic response of the reactor vessel system to a postulated LOCA in a BWR, while the thermal-hydraulic response of the hot assembly is computed by the DRAGON code. Boundary conditions from the GOBLIN calculation are used in the hot assembly analysis. Finally the CHACHA-3C code is used to calculate the detailed fuel rod heat-up analysis at a specified elevation using boundary conditions taken from the DRAGON hot assembly calculation.

ABB/CE designated the NRC approved LOCA codes, the GOBLIN code series, in the topical report RPB-90-93-A (Ref. 2) as ".USA1". Therefore, the GOBLIN code is referred to as GOBLIN.USA1 and the rest of the code series is similarly designated. The code series used in qualification and sensitivity studies documented in this topical report bears the "USA1" designation since it is the same code reviewed in Reference 2.

2.2 SVEA Fuel Assemblies

Design aspects of SVEA-96 fuel are documented in CENPD-285 and 287 which are being reviewed separately (Refs. 5 and 6). Major differences between SVEA-64 and -96 are that the SVEA-64 fuel assembly contains 64 fuel rods in a 8x8 configuration with a cruciform structure, whereas SVEA-96 contains 96 fuel rods configured in four sub-bundles of 5 x 5 minus the central rod, separated from the other sub-bundles with wings and a central water box which form the crucifix. The SVEA-96 water cross-flow area is slightly larger than the SVEA-64 design (by 1.8%).

The linear heat generation rate is lower in SVEA-96 fuel than in SVEA-64 due to the smaller fuel rods in the assembly.

ABB's procedure to determine hydraulic compatibility of fuels is documented in CENPD-300 (Ref. 7) and reviewed separately.

2.3 Restrictions Cited in RPB 90-93-P-A

In the SER for RPB 90-93-P-A (Ref. 2), on which the methodology described in CENPD-283-P is based, certain conditions/restrictions were cited which ABB/CE addressed. These are:

1. Statement of conformity to plant-specific requirements of Appendix K for use in licensing calculations applied to a reload safety analysis report, including a sensitivity study;

2. Only staff-approved CHF correlation may be used when the subject ECCS methodology is used in a licensing analysis. Furthermore, the experimental data used to verify the convective spray heat transfer coefficients should be justified as applicable to the particular fuel design for which the overall methodology is to be applied.

3. The use of a fuel design other than QUAD+/SVEA-64 fuel in a transition core should also be addressed.

ABB/CE performed and presented sensitivity studies to address these above mentioned issues. With respect to the critical power ratio (CPR) correlation, ABB/CE intends to use a new CPR correlation for SVEA-96, XL-S96, which has been approved in UR-89-210-P-A (Ref. 8). However, ABB/CE chose to demonstrate the adequacy of implementation into the GOBLIN series in connection with review of CENPD-293-P and therefore it will not be reviewed here.

Justification of the choice of convective spray heat transfer coefficients for use with SVEA-96 is presented in this topical report in order to demonstrate conformity to the acceptance criteria of 10 CFR 50 Appendix K.

Applicability of certain models and changes in input due to SVEA-96 were examined through performance of sensitivity studies. Their impacts upon overall transient results were assessed, and the description and qualification are documented.

3.0 EVALUATION

In this report, thje designation ".USA1" is not used.

3.1 Reference Plant

For the purpose of performing sensitivity studies, a reference plant model was selected using a GE BWR/5 plant design with a SVEA-96 core. Changes in input and code model selection, described in Section 3.2 of this report, were incorporated into the reference model. The accident scenario chosen for this purpose is a full guillotine break of a recirculation suction line with failure of the low pressure core spray diesel generator.

Computed transient response was examined with respect to each code segment: system response with GOBLIN, hot fuel assembly response with DRAGON and the hot axial plane fuel rod heatup response with the CHACHA-3C code.

3.2 Application of Approved Methodology to SVEA-96 Fuel Designs

Sensitivity studies were performed using the reference plant described above with respect to applicability to LOCA analysis with SVEA-96 fuel of certain models which are fuel design dependant in the approved methodology, since the approved methodology was qualified for LOCA analysis application with SVEA-64/QUAD+. Additional changes were also documented in the subject topical report supplement.

a. SVEA-96 Nodalizations

Due to significant changes in SVEA-96 fuel assembly geometry, additional fuel channel nodalization sensitivity studies were performed with GOBLIN, DRAGON and CHACHA-3C.

With GOBLIN, the impact on analysis of modeling a cruciform was assessed. In SVEA-64 modeling, the cruciform was modeled as a single water channel. For SVEA-96 fuel assembly, two different nodalizations of the cruciform were considered: one in which a single channel modeled wings and the central box; a second in which two separate channels representing the central box and the combined four wings. In addition, the impact from the upper plenum level tracking was examined.

Sensitivity study results showed that there was little difference between calculational results using the two cruciform models. Similarly the contribution from the use of level tracking was determined to be minimal.

A typical DRAGON nodalization for SVEA-64, therefore, was adopted for SVEA-96 with additional flow paths from the water channel to the fuel rods. Comparison of DRAGON and GOBLIN predicted system parameters agreed well. Similarly, the standard CHACHA-3C fuel rod nodalization was used for SVEA-96 sensitivity studies in which ABB/CE concluded that the sensitivity due to the parameter studied was negligible.

b. CPR Correlation and Implementation

The SER on UR-89-210-P-A (Ref. 8) approved the use of the XL-S96 CPR correlation with the BISON computer code; however, that Reference 9 requires that when this correlation is implemented in other computer codes, the vendor must submit to the NRC documentation of adequate implementation. In addition, the SER requires that the correlation be used to evaluate the SVEA-96 fuel assemblies for the revised range of applicability.

Although it was required in the SER (Ref. 9) for UR 89-210-P-A that ABB/CE present results demonstrating that the XL-S94 CPR correlation was properly implemented in GOBLIN/DRAGON code, ABB/CE chose not to do that at this time and review should be performed as part of review of CENPD-293-P (Ref. 10). This is because ABB/CE views this version of GOBLIN/DRAGON/CHACHA-3C to be an intermediary state, and, in CENPD-292, ABB/CE documented additional model improvements made to the GOBLIN/DRAGON/CHACHA-3C codes.

Therefore, review of the XL-S94 CPR correlation implementation was not performed as part of this review.

c. Countercurrent Flow Limit (CCFL) Option

ABB developed a CCFL model based on a form of the Wallis correlation. Determination of constants in the CCFL model was presented in Reference 4. ABB demonstrated in Reference 2 that the CCFL model used for SVEA-64 was adequately conservative against the test data. In extending the same model for use with SVEA-96, ABB stated that CCFL is not a significant determinant of the system or core behavior for the transient analyzed in the sensitivity studies.

d. Convective Spray Heat Transfer Coefficients

10 CFR 50.46 Appendix K specifically states the allowable values for

convective heat transfer coefficients during spray cooling for certain fuel designs and when computations must be supported by experimental data.

The convective heat transfer coefficients applicable to SVEA-96 fuel are determined by a procedure (Refs. 1 and 3) which accounts for anisotropic effects and which has been validated through experiments for several other fuel designs. That procedure was applied to develop coefficients for SVEA-64 fuel by conversion of the values stated in 10CFR50 Appendix K. The transformed values were compared against the test data and were shown to be conservative for SVEA-64. ABB asserts that the coefficients developed for SVEA-64 can be applied for use in SVEA-96 analysis and will always produce conservative results because: (i) they were demonstrated to be conservative when compared to the experimental data for SVEA-64; (ii) the principal reason for the conservatism was the existence of the watercross in SVEA-64 fuel, and SVEA-96 fuel also has watercross; (iii) radiative heat transfer is well predicted with an anisotropic model for either fuel and therefore can be assumed to be equally conservative for SVEA-96 as it is for SVEA-64; and (iv) ABB demonstrated through sensitivity studies that a large change in the values of convective spray heat transfer coefficients resulted in a small change in computed peak cladding temperature.

3.3 Mixed Core Effects

ABB presented comparative results of analysis of cores containing QUAD+, 8x8R and SVEA-96 and a transition core from 8x8R to QUAD+. The results supported ABB's conclusions that the core average system response is relatively independent of local differences in fuel assembly design during a LOCA event.

4.0 CONCLUSION

ABB/CE's topical report "Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Sensitivity for SVEA-96 Fuel," CENPD-283-P, dated March 1993 and supplemental information provided by the vendor in support of its submittal were reviewed. Review was also performed to assure that the limitations and restrictions cited in the RPB-90-93-P-A are adequately addressed.

The review focus was upon examination of ABB's sensitivity studies and discussion of the adequacy of selected options and input for licensing type applications. This review did not include evaluation of the adequacy of implementation of the XL-S96 CPR correlation, since the vendor chose to address this issue in CENPD-293-P.

We find that the vendor has adequately demonstrated the reasonably conservative nature of its modified ECCS methodology for SVEA-96 fuel using GOBLIN/DRAGON/CHACHA-3C, subject to the limitations and recommendations set forth below:

1. It is recommended that approval of the methodology documented in CENPD-283-P be granted only for use with SVEA-96 fuel and not for other fuel designs.

2. The convective spray heat transfer coefficients selected for SVEA-96 fuel are not directly supported by experimental data. ABB/CE extended the procedure used in selection of the convective spray heat transfer coefficients for SVEA-64 from 7x7 and 8x8 fuel assembly data. Because the sensitivity studies indicated that the PCT is insensitive to the convective spray HT coefficient and because the coefficients used for SVEA-64 are well supported by the experimental data, the selection of convective spray coefficients for SVEA-96 fuel to be those values used for SVEA-64 fuel is acceptable for use with SVEA-96 for LOCA analysis. However, it is not recommended that the same procedure be extended further to other fuel without being directly supported and validated by experimental data.

3. Similarly, because the coefficients in ABB's CCFL option in GOBLIN are supported by experimental data for SVEA-64 fuel and the sensitivity studies indicate that the predicted system and core behavior is insensitive to the values of these coefficients, the CCFL option in GOBLIN is acceptable for use with SVEA-96 fuel in LOCA analysis. However, extending further to other fuels should be validated by experimental data for those particular fuels.

4. The predicted system parameters were demonstrated to be insensitive to the selected CCFL and convective spray heat transfer coefficients for analyses that resulted in PCTs in the range of 1500-1600°F. However, we recommend that the vendor be required to demonstrate the acceptability of both of these in any instance when the computed PCT approaches the Appendix K limit.

5. The overall acceptability of ABB's ECCS methodology for BWR remains subject to the restrictions and limitations of all other governing SERs of relevant computer codes, models and fuel designs and their previously approvals.

5.0 REFERENCES

1) "Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Sensitivity for SVEA-96 Fuel," CENPD-283-P, March 1993.

2) "Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Description and Qualification," ABB RPB 90-93-P-A, October 1991.

3) "Transmittal of CENPD-283-P-RAI, Rev. 1 Providing Response to NRC Request for Additional Information on "BWR ECCS Evaluation Model: Response to Request for Additional Information on Code Sensitivity for SVEA-96 Fuel," August 9, 1995.

4) "Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Sensitivity," ABB RPB 90-94-P-A, October 1991.

5) Fuel Rod Design Methods for Boiling Water Reactors," CENPD-285-P, May 1994.

6) "Fuel Assembly Mechanical Design Methodology for Boiling Water Reactors," CENPD-287-P, June 1994.

7) "Reference Safety Report for Boiling Water Reactor Reload Fuel," CENPD-300-P, November 1994.

8) "SVEA-96 Critical Power Experiments on a Full Scale Sub-bundle," ABB Atom Report UR 89-210-P-A, October 1993.

9) Memorandum from A.C. Thadani to W.R. Russell, "Waiver of CRGR Review of the Safety Evaluation of ABB CE Supplemental Information Regarding UR 89-210 Safety Evaluation Report," July 12, 1993.

10) "BWR ECCS Evaluation Model: Supplement 1 to Code Description and Qualification," CENPD-293-P, August 1994.

CENPD-283-NP-A REPORT

Part II

Body of Report

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1 INTRODUCTION

The GOBLIN system of computer codes is used by ABB to evaluate Emergency Core Cooling System (ECCS) performance in boiling water reactors (BWR). The codes and methodology have been approved by the U. S. NRC and are described in detail, in References 1, 2, and 3. The methodology was demonstrated for the SVEA-64/QUAD+ fuel design* in a BWR/5,6 plant design. Extension of the methods to other plants and fuel designs requires additional sensitivity calculations. This report presents results of Loss of Coolant Accident (LOCA) sensitivity studies which have been performed by ABB to generically extend the LOCA Evaluation Model application to licensing calculations with SVEA-96 fuel.

The analyses presented here are a straight extension of the sensitivity studies performed in Reference 1. A systematic assessment of the impact of LOCA modeling on calculational results for a reference plant design are addressed. The results of the sensitivity studies are used to define the LOCA evaluation methodology which conforms to the acceptance criteria of 10 CFR 50.46 and Appendix K (Reference 5). A flow chart of this strategy is shown in Figure 1.1. Examples of "models based on test data" from Figure 1.1 include correlations for heat transfer coefficients, countercurrent flow limitation, dryout and pressure drop. Examples of "generic sensitivity studies" include time step, convergence criteria and some noding sensitivity studies (e.g. core, rod, and channel noding). The approach in Figure 1.1 is applicable to any BWR plant type. The extension of this approach to SVEA-96 fuel is described in this report.

Section 2 provides a brief overview of the GOBLIN series of computer codes used in ABB BWR LOCA analyses. Section 3 describes SVEA-96 fuel and how it compares to the SVEA-64/QUAD+ design from the perspective of ECCS analysis. Section 4 describes the new models and inputs required for modeling SVEA-96 fuel. Section 5 describes the results for the limiting break in the reference BWR/5 with SVEA-96 fuel. This transient serves as the reference case for the sensitivities presented in the remainder of the report. Sections 6 and 7 provide justification for the evaluation methodology by examining the sensitivity of the LOCA results to key modeling assumptions and code inputs. Finally, Section 8 addresses the impact of mixed fuel designs on BWR LOCA transient.

* QUAD+ fuel design was the Westinghouse equivalent product to the ABB SVEA-64 fuel design.

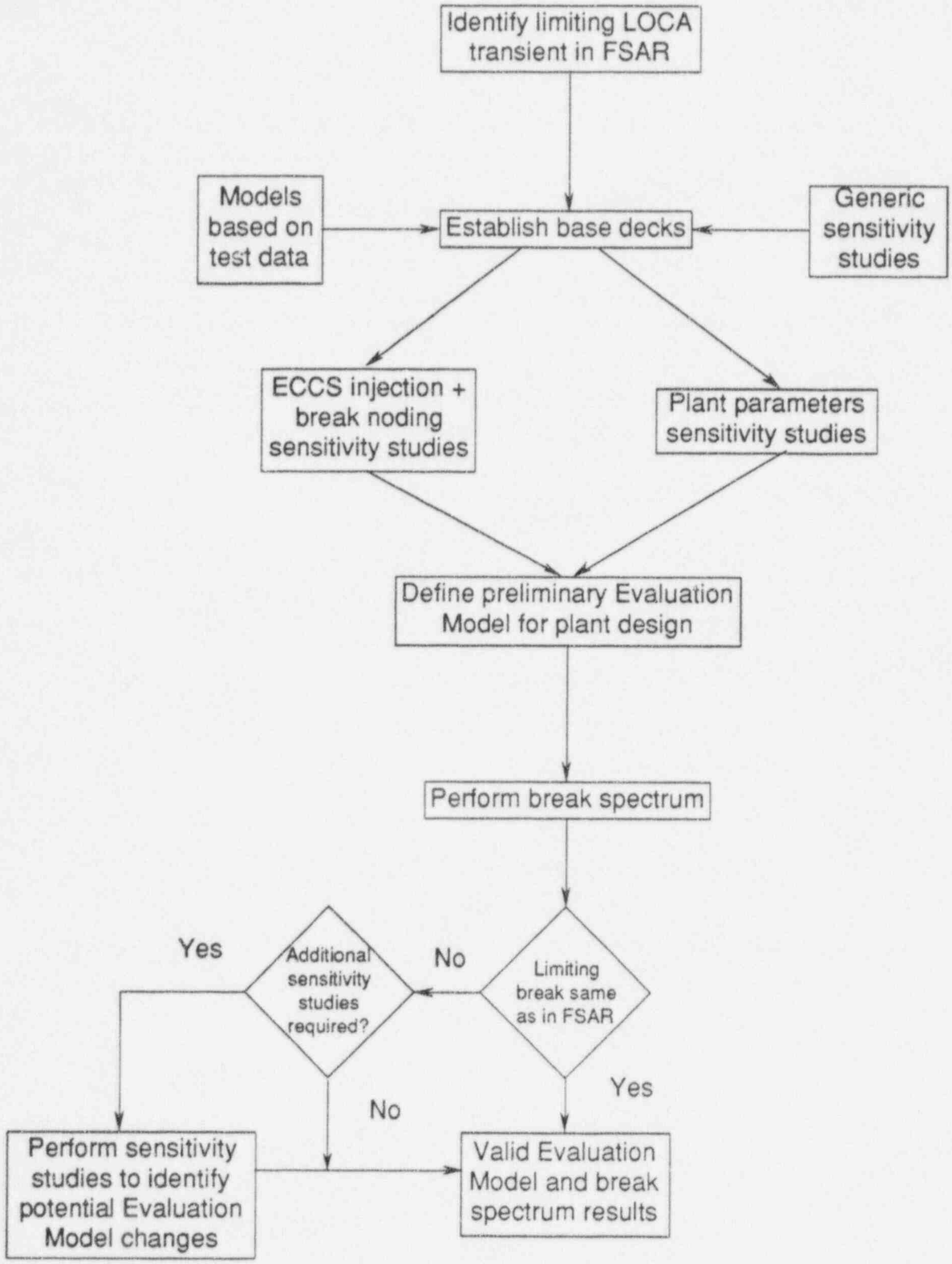

Figure 1.1 Method Used to Define LOCA Evaluation Model

2 OVERVIEW OF COMPUTER CODES

The GOBLIN series of computer codes uses one-dimensional assumptions and solution techniques to calculate the BWR transient response to both large and small break LOCAs. The series is composed of three major computer codes -- GOBLIN, DRAGON, and CHACHA-3C. The function of the individual codes are:

GOBLIN - Performs the analysis of the LOCA blowdown and reflood thermal hydraulic transient for the entire reactor, including the interaction with various control and safety systems.

DRAGON - Performs the hot fuel assembly thermal hydraulic transient calculations using boundary conditions from the GOBLIN calculation. (DRAGON is virtually identical to GOBLIN, the only difference is that several calculation models are bypassed in DRAGON.)

CHACHA-3C - Performs detailed fuel rod mechanical and thermal response calculations at a specified axial level within the fuel assembly previously analyzed by the DRAGON code. All necessary fluid boundary conditions are obtained from the DRAGON calculation. CHACHA-3C determines the temperature distribution of each rod throughout the transient and ultimately the peak clad temperature (PCT) and cladding oxidation at the axial plane under investigation. It also provides input for the calculation of total hydrogen generation.

The flow of information between these codes is shown in Figure 2.1. Detailed code descriptions may be found in Reference 2.

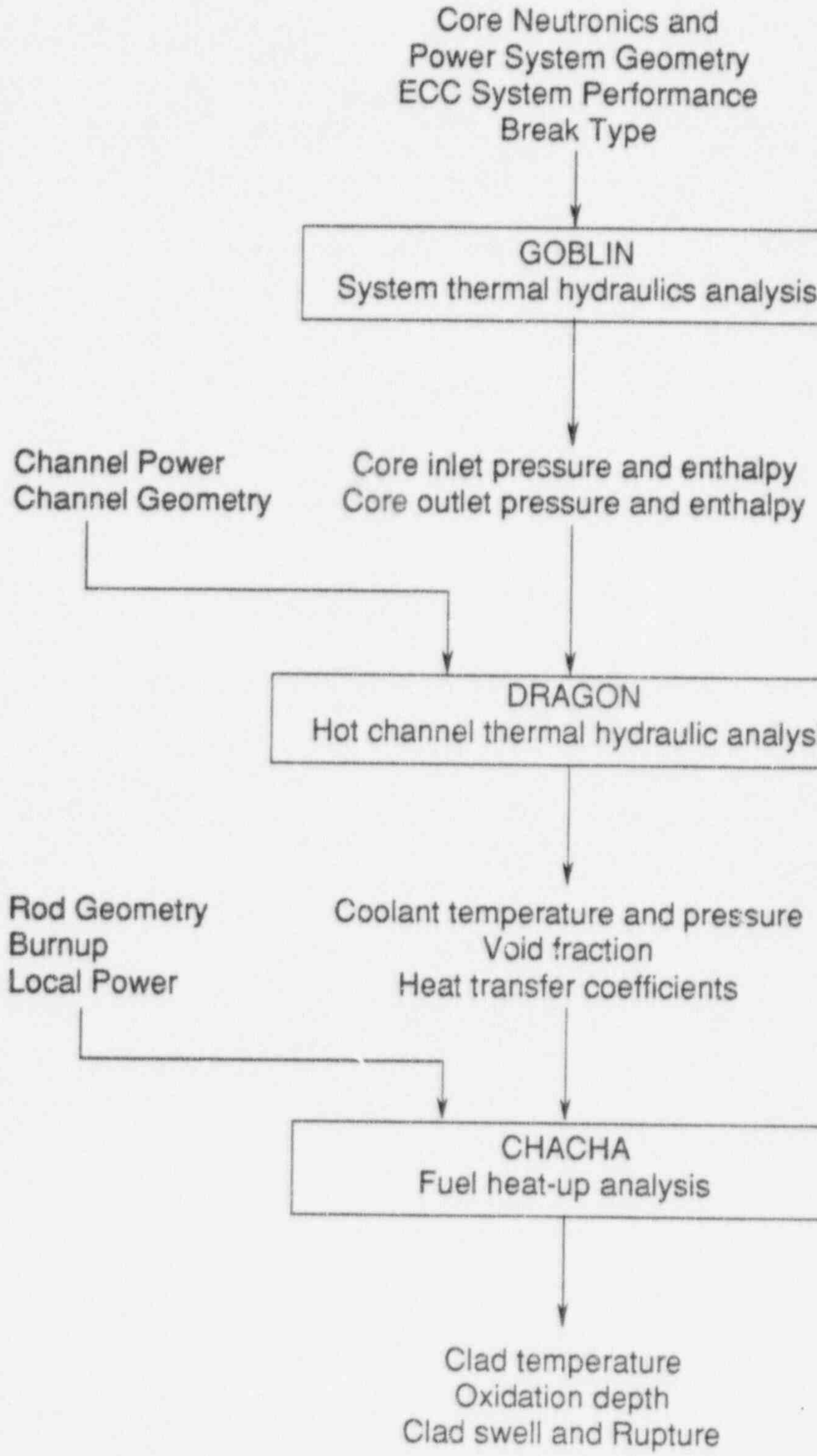

Figure 2.1 Flow of Information Between Computer Codes

3 OVERVIEW OF SVEA-96 FUEL

Application of the ABB LOCA Evaluation Model was defined in Reference 1 for the SVEA-64/QUAD+ fuel design. This section briefly describes the ABB SVEA-96 fuel design in comparison to the SVEA-64/QUAD+ fuel design. The description focuses on features which pertain to ECCS analyses. The SVEA-64/QUAD+ fuel is described in detail in Reference 3. A complete description of the SVEA-96 fuel design is contained in Reference 4.

3.1 SVEA-96 Fuel Assembly

The SVEA-96 fuel assembly consists of 96 fuel rods, arranged in four 5x5-1 sub-bundles, and a fuel channel (see Figure 3.1). The fuel channel has a cruciform internal structure, that forms a gap for non-boiling water during operation. The sub-bundles are inserted from the top and are freestanding inside the fuel channel. There is sufficient space for the linear thermal expansion of the sub-bundles within the fuel channel. The cruciform structure helps to support the channel walls and reduces stresses and deformation. The cruciform consists of a center box and four wings. The central water gap is completely separated from the subbundles. Water enters the center box through an orifice just below the lower tie plate and exits through a full opening at the top of the channel, above the upper tie plates (Figure 3.2). Water enters the wings by flow holes in the side of the each wing just above the lower tie plate and exits through a full opening at the same elevation as the center box. Some key SVEA-96 design parameters are shown in Table 3.1.

3.2 Comparison to SVEA-64/QUAD+ Fuel Design

The SVEA-64/QUAD+ fuel assembly, for which LOCA sensitivity studies have been previously performed, consists of 64 fuel rods, arranged in four 4 x 4 mini-bundles with a fuel channel. This fuel assembly also has an internal structure that provides non-boiling water during operation, and segregates the mini-bundles (see Figure 3.3). The internal structure is a simpler, single cruciform structure. Watercross water is introduced through an orifice just below the lower tie plate, and exits through a full opening just below the upper tie plate. The SVEA-64/QUAD+ fuel design parameters are also listed in Table 3.1. Section 2.2 of Reference 3 describes SVEA-64/QUAD+ fuel in detail.

TABLE 3.1

FUEL DESIGN PARAMETERS

	UNITS	QUAD+	SVEA-96
Fuel Array		four 4x4	four 5x5-1
Number Rods		64	96
Total Length	cm (inch)	406.1 (159.9)	414.8 (163.3)
Active Length	cm (inch)	381 (150)	381 (150)
Rod Outside Diameter	cm (inch)	[#	#]
Cladding Thickness	cm (inch)	#	#
Rod Pitch	cm (inch)	#	#
Number Spacers		6	6
Channel Thickness	cm (inch)	[#	#]
Active Fuel Flow Area	cm^2 ($inch^2$)	#	#
Water Gap Flow Area	cm^2 ($inch^2$)	#	#
Upper Tie Plate Area	cm^2 ($inch^2$)	#	#

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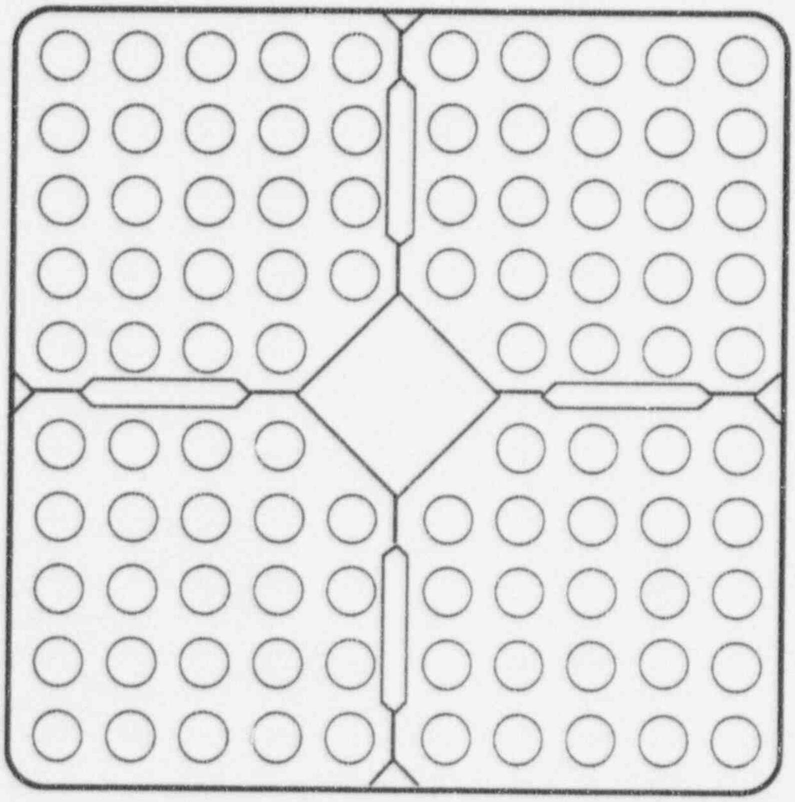

Figure 3.1 SVEA-96 Fuel Design

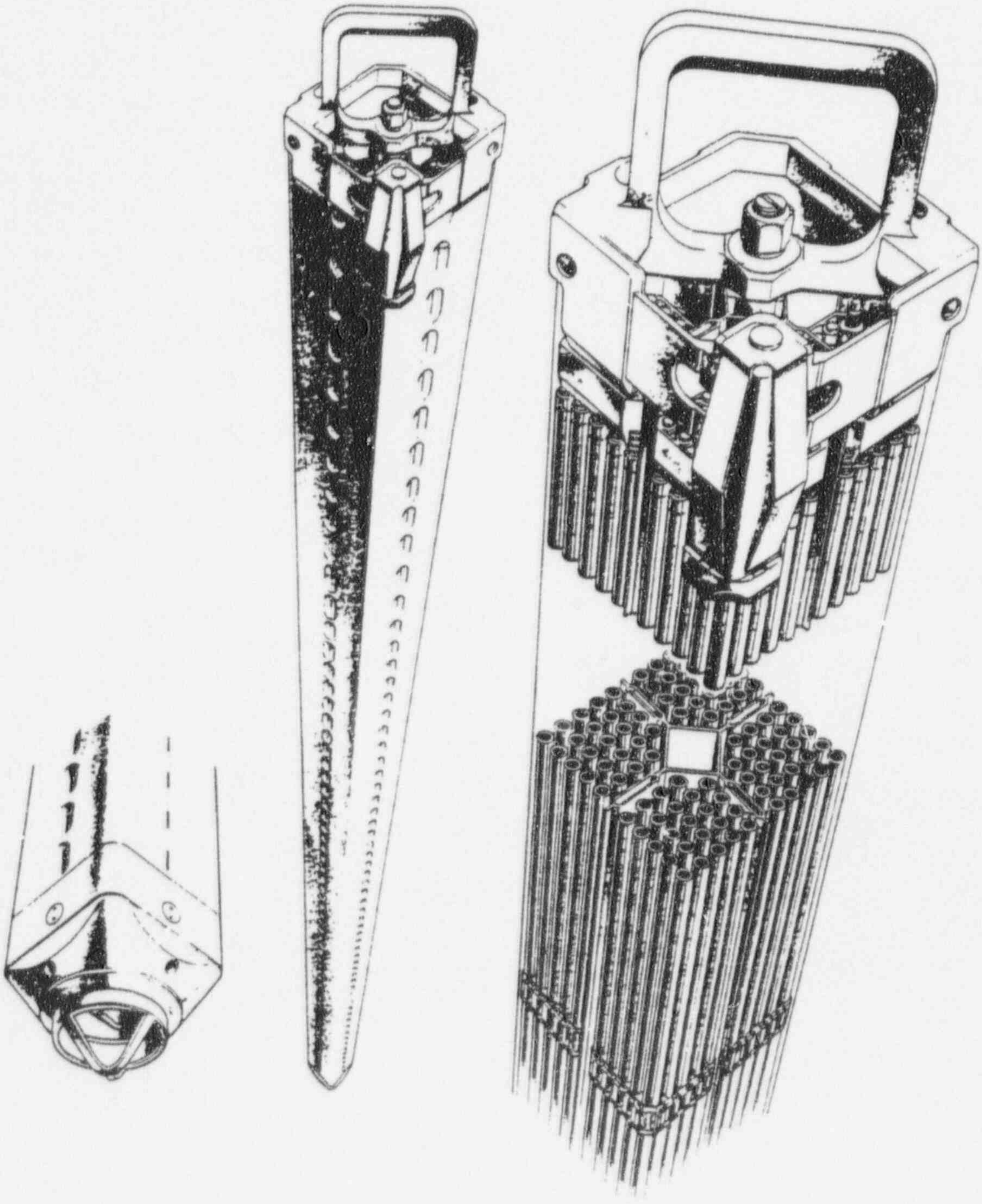

Figure 3.2 SVEA-96 Fuel Assembly

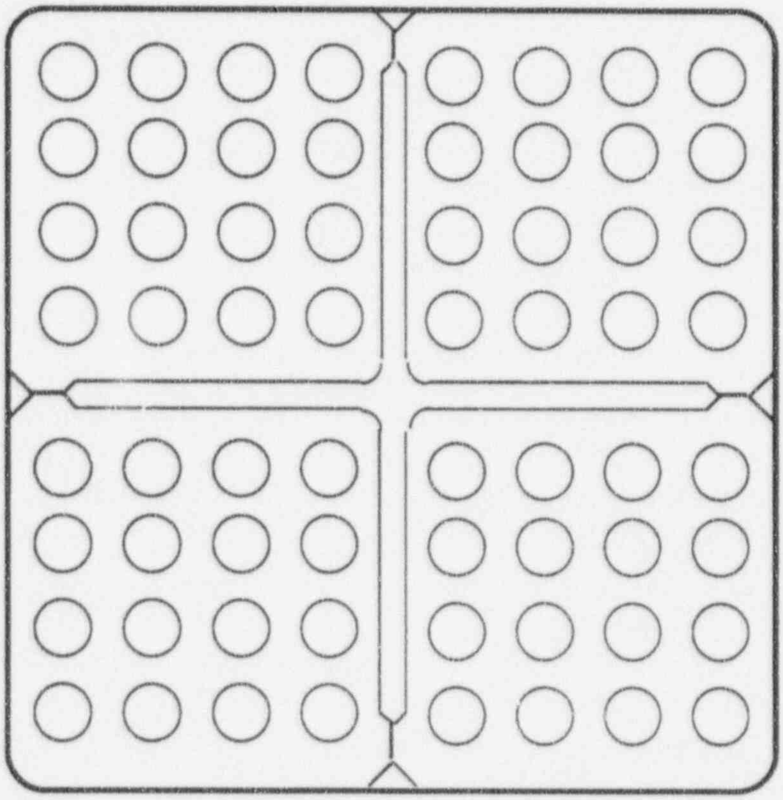

Figure 3.3 SVEA-64/QUAD+ Fuel Design

4 NEW MODELS AND INPUTS FOR SVEA-96 FUEL

The new SVEA-96 fuel design requires several changes in the previously approved LOCA analysis methodology. Additional fuel channel nodalization sensitivity studies need to be performed. A new correlations is required for CPR performance. Also required are spray heat transfer coefficients applicable to SVEA-96 fuel.

4.1 SVEA-96 Nodalizations

From the view of LOCA analyses, the SVEA-96 and SVEA-64 fuel designs are very similar. They both have four active fuel mini-bundles and a non-boiling center channel. The SVEA-96 design differs from SVEA-64/QUAD+ in that it has separate, non-communicating wings and center channel flows. Modeling of this design change is defined by sensitivity studies of alternate nodalizations.

4.2 CPR Correlation and Implementation

The SVEA-96 critical power correlation was developed through a full scale thermal-hydraulic verification program in the ABB Atom FRIGG loop. The resultant correlation is documented in Reference 7. Reference 7 has been approved by the U.S. NRC. This correlation, denoted by XL-S96, is implemented into the GOBLIN/DRAGON code. The implementation is analogous to the previous approved QUAD+ CPR correlation application.

4.3 SVEA-96 Convective Spray Heat Transfer Coefficients

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5 REFERENCE LOCA

In this section the reference LOCA transient response is described in detail. The reference plant type analyzed is a General Electric BWR/5 plant design. Figure 5.1 shows a schematic diagram of the BWR/5 vessel, internals, and recirculation system. Table 5.1 summarizes some key features of the reference plant analyzed.

5.1 Accident Description

The reference LOCA transient is a full guillotine break of a recirculation suction line in a BWR/5 plant. This reference transient assumes failure of the low pressure core spray diesel generator (Division I) which results in the limiting break for a BWR/5 plant. The emergency cooling systems for the example BWR/5 plant is shown in Figure 5.2. The ECC systems of interest are the high pressure core spray (HPCS), low pressure core spray (LPCS), and low pressure coolant injection (LPCI).

The transient response is described in three sections. First described is the system response calculated with the GOBLIN code. Next described is the hot fuel assembly response calculated with the DRAGON code. Last presented is the hot axial plane fuel rod heatup response calculated with the CHACHA-3C code.

5.2 Reactor System Response

The GOBLIN code is used to calculate the reactor vessel system response to a postulated LOCA in a BWR. The reference GOBLIN nodalization is shown in Figure 5.3. The LOCA analysis is initiated from 104.3 percent of rated full power, a pressure of 72.7 bar (1055 psia), and 100 percent of rated core flow. The LOCA is initiated at time zero by an instantaneous 100 percent guillotine break in a recirculation suction line. Also at time zero, offsite power is assumed lost, which causes tripping of the two main recirculation pumps. Reactor scram and MSIV closure occur in the first second of the transient from low water level.

Figure 5.4 shows the initial vessel pressure response and subsequent depressurization. The initial pressure response is governed by the time of reactor scram, MSIV closure and jet pump suction uncovery. In the reference transient the pressure initially drops due to the inventory loss out the break and steamlines. When the MSIVs are closed, the vessel pressure recovers and starts to pressurize until the jet pump suction uncovers. Once the downcomer level falls below the top of the jet pumps a steam vent path is created out the break, increasing the volumetric inventory loss. This stops the short-lived vessel repressurization. About two seconds after jet pump uncovery, the recirculation line uncovers, significantly increasing the volumetric flow out the break. The recirculation line uncovery causes a subsequent rapid depressurization to near atmospheric pressure in about 60 seconds.

Figure 5.5 shows the total break mass flow rate. Although the break mass flow rate decreases after the downcomer empties (at about 8 seconds), the break volumetric flow rate increases due to steam venting out the break. Hence the pressure vessel depressurizes faster.

Figure 5.6 shows the active core inlet flow rate during the initial phase of the transient. Several key phenomena are visible in this plot. They include jet pump uncovery, jet pump flashing and lower plenum flashing. The core inlet flow drops off rapidly in the initial seconds due to the loss of the broken recirculation line drive flow and initial coastdown of the intact recirculation loop. At about six seconds the jet pump suctions uncover, further degrading the intact jet pump performance. Less than a second later the vessel pressure has dropped to the point where the jet pump fluid saturates and flashes, causing a surge in core inlet flow. At about nine seconds the lower plenum fluid flashes, causing a larger surge in core inlet flow rate. The lower plenum continues to flash at a slower rate for the next eight seconds. This is evident by the slow decay in the core inlet flow rate.

Figure 5.7 shows the total core side entry orifice inlet flow rate. The results show the initial flow rate decrease, periods of fluid flashing, and the subsequent draining of the core through the lower plenum and out the break.

The vessel draining, ECC system actuation, and subsequent refilling and reflooding of the vessel regions can be seen in Figures 5.8 and 5.9. Figure 5.8 shows the total system mass inventory. As can be seen in the figure, HPCS actuation does not compensate for the inventory loss out the break. However, once the LPCI is actuated the vessel inventory starts to be replenished. The mass inventory distribution in the reactor vessel can be seen in Figure 5.9. The guide tubes refill first at 123 second then the lower plenum at 126 seconds, followed by the bypass region at 152 seconds. The core and upper plenum are last to refill.

Figure 5.10 shows the mixture levels in the downcomer, upper plenum and lower plenum. The mixture levels show the downcomer and lower plenum draining and subsequent refill processes. The downcomer mixture level increases from 120 to 150 along with the core refilling. However, the downcomer is still highly voided as shown by the mass inventory in Figure 5.9. The upper plenum level tracking is deactivated resulting in fixed boundaries. Tracking the upper plenum mixture level is not warranted with the detailed noding employed, and is conservative as discussed later.

The timing of the key events in the system response analysis are summarized in Table 5.2. The observed LOCA system response with SVEA-96 presented here, is very similar to the response with SVEA-64/QUAD+ fuel presented in Reference 1. The next section gives a detailed description of the hot assembly thermal-hydraulic response.

5.3 Hot Assembly Response

The DRAGON code is used to calculate the thermal and hydraulic response of the hot assembly in a BWR during a postulated LOCA. Boundary conditions from the GOBLIN calculation are used in the hot assembly analysis. They are the plenum pressures and enthalpies, core power, and bypass fluid properties. The lower plenum and upper plenum enthalpy boundary conditions from the GOBLIN reference transient are shown in Figures 5.11 and 5.12. The core pressure drop boundary condition is shown in Figure 5.13.

The DRAGON hot assembly noding used in the ABB evaluation model is shown in Figure 5.14. The fuel rod conduction model considers 5 rod groups in the assembly (see Figure 5.15). The choice of the DRAGON rod grouping has no impact on an Appendix K analysis, since all rods are assumed to dry out at the same time as the lead rod. However, this rod grouping does provide a preliminary look at the bundle radial temperature profile.

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The key results from the reference DRAGON transient are shown in Table 5.3 and Figures 5.16 through 5.19. The hot assembly active channel inlet flow follows the GOBLIN results closely (Figure 5.16 vs. Figure 5.6). The hot channel midplane dryout is calculated to occur at 24 seconds. The average power channel midplane dryout is calculated at 22 seconds. The average channel dryout is earlier only because the low flow limit of validity for the dryout correlation is reached sooner. Once outside the correlation range of validity a conservative pool boiling correlation is used. The void fraction at the bundle midplane is shown in Figure 5.17. This figure shows the timing of midplane core uncovery and reflood. Cladding temperature turnaround at midplane reflood occurs at the same time as in the GOBLIN transient (Table 5.2). Bundle mass inventory throughout the transient is shown in Figure 5.18, and follows the GOBLIN average core inventory trend (Figure 5.9).

The DRAGON hot channel results which are passed to CHACHA-3C for use in the rod heatup calculations are coolant pressure, rod heat transfer coefficients prior to uncovery, and reflood time. The coolant pressure and rod heat transfer coefficients for the midplane are shown in Figures 5.19 and 5.20. The uncovery time is defined as the time at which the transition from the film boiling heat transfer regime to steam cooling begins. The reflood time is defined as the time at which the DRAGON temperature transient is mitigated by the transition from steam cooling to the low flow film boiling heat transfer regime. Therefore, the reflood time is the same as the DRAGON cladding temperature turnaround time.

5.4 CHACHA-3C Reference Transient

The CHACHA-3C code is used to perform the detailed fuel rod heatup calculations at a specified elevation from the hot assembly analysis. The reference CHACHA-3C calculation has been performed using boundary conditions from the midplane of the reference DRAGON transient (Figures 5.19 and 5.20). A typical SVEA-96 fuel design for a jet pump BWR was considered as the reference design.

Nuclear and fuel rod performance data corresponding to an average planar burnup of 22,000 MWd/MTU were used in the reference CHACHA-3C transient. This burnup is conservative for the reference fuel design for several reasons:

1. The gadolinium has been depleted to the point where the interior rods are operating at relatively high powers. Higher interior rod peaking factors yield higher peak cladding temperatures for a given planar linear heat generation rate.

2. The maximum local peaking factor for the assembly is very close to unity. Therefore the planar linear heat generation rate is close to the maximum linear heat generation rate.

3. Rod internal pressure is higher than at lower burnups, increasing the likelihood of burst.

4. Typically, beyond approximately this burnup the fuel can no longer achieve limiting power levels.

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TABLE 5.1

REFERENCE PLANT DESIGN FEATURES

Plant Type	GE BWR/5
Number of Fuel Assemblies	764
Fuel Design	SVEA-96
Recirculation Lines	2
Number of Jet Pumps	20
Rated Power	3,323 MWt
Rated Steam Flow	1801 kg/sec (14.3 x 10^6 lbm/hr)
Rated Core Flow	13,700 kg/sec (108.5 x 10^6 lbm/hr)
Steam Dome Pressure	70.3 bar (1020 psia)
Feedwater Temperature	215°C (420°F)

TABLE 5.2

TIMING OF SYSTEM RESPONSE KEY EVENTS

	Time (sec)
Break Initiates	0
Reactor Scram/MSIVs Begin to Close	1
MSIVs Closed	[illegible]
Jet Pumps Uncover	5.9
Jet Pump Flashing	6.3
Downcomer Level Below Break Elevation	8
Lower Plenum Flashing	9.1
Avg. Channel Midplane Dryout	22
HPCS Initiation	27
Initiation of Spray Cooling	48
LPCI Initiation	53
Guide Tubes Full	123
LP Full	126
Midplane Reflood	149
Bypass Full	152

TABLE 5.3

TIMING OF HOT ASSEMBLY KEY EVENTS

	Time (sec)
First Dryout	1.5
Midplane Dryout	24.
Midplane Uncovery	32.
Midplane Reflood	149.

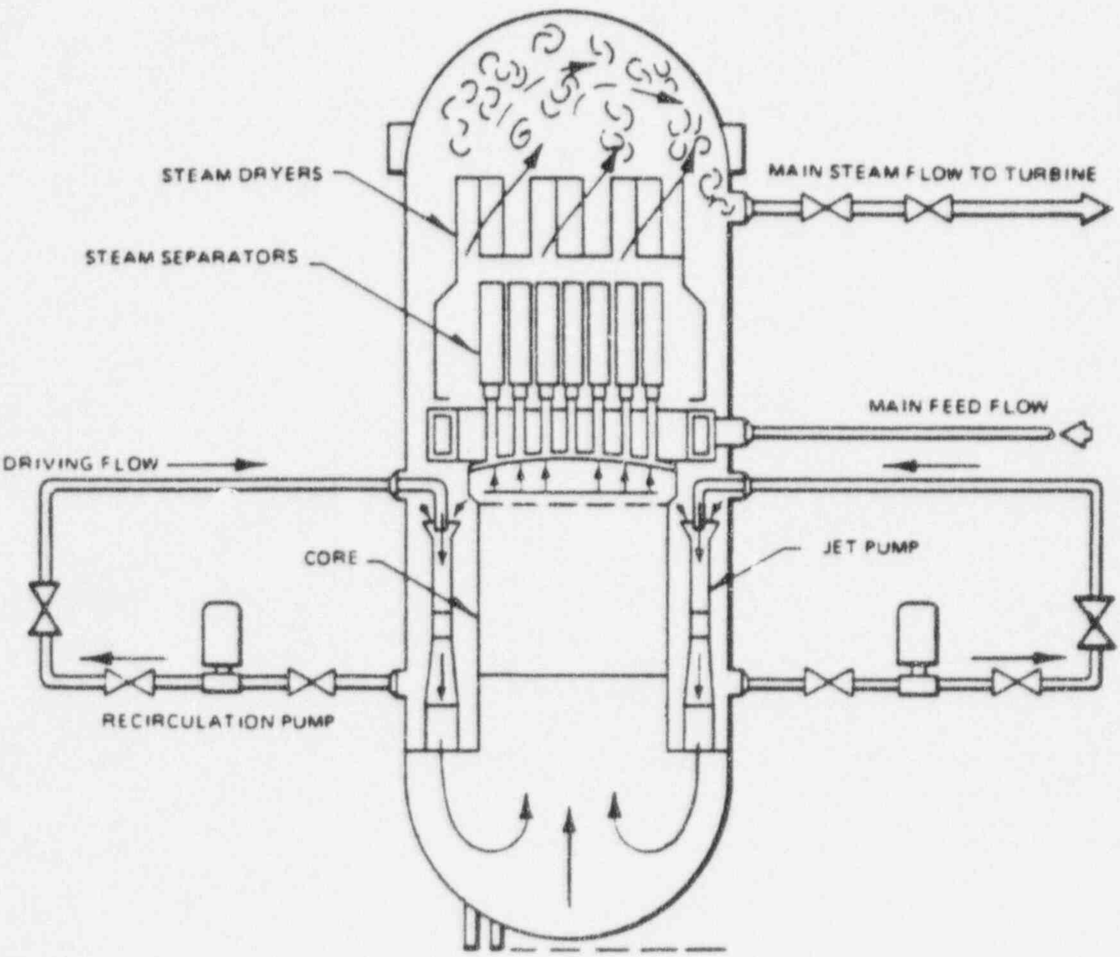

Figure 5.1 Jet Pump Boiling Water Reactor

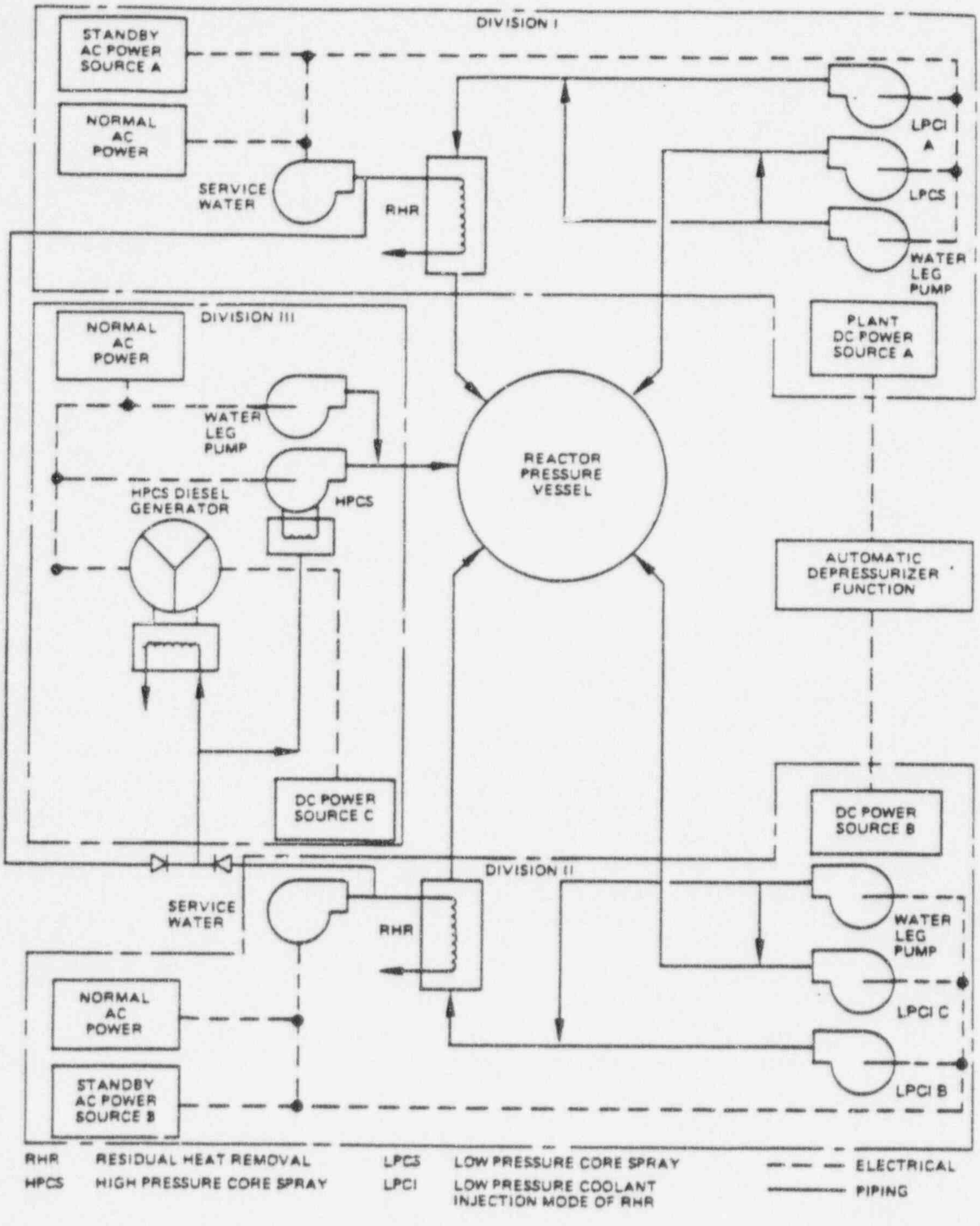

Figure 5.2 Emergency Cooling System Network for BWR/5

FIGURE 5.3 THROUGH FIGURE 5.15

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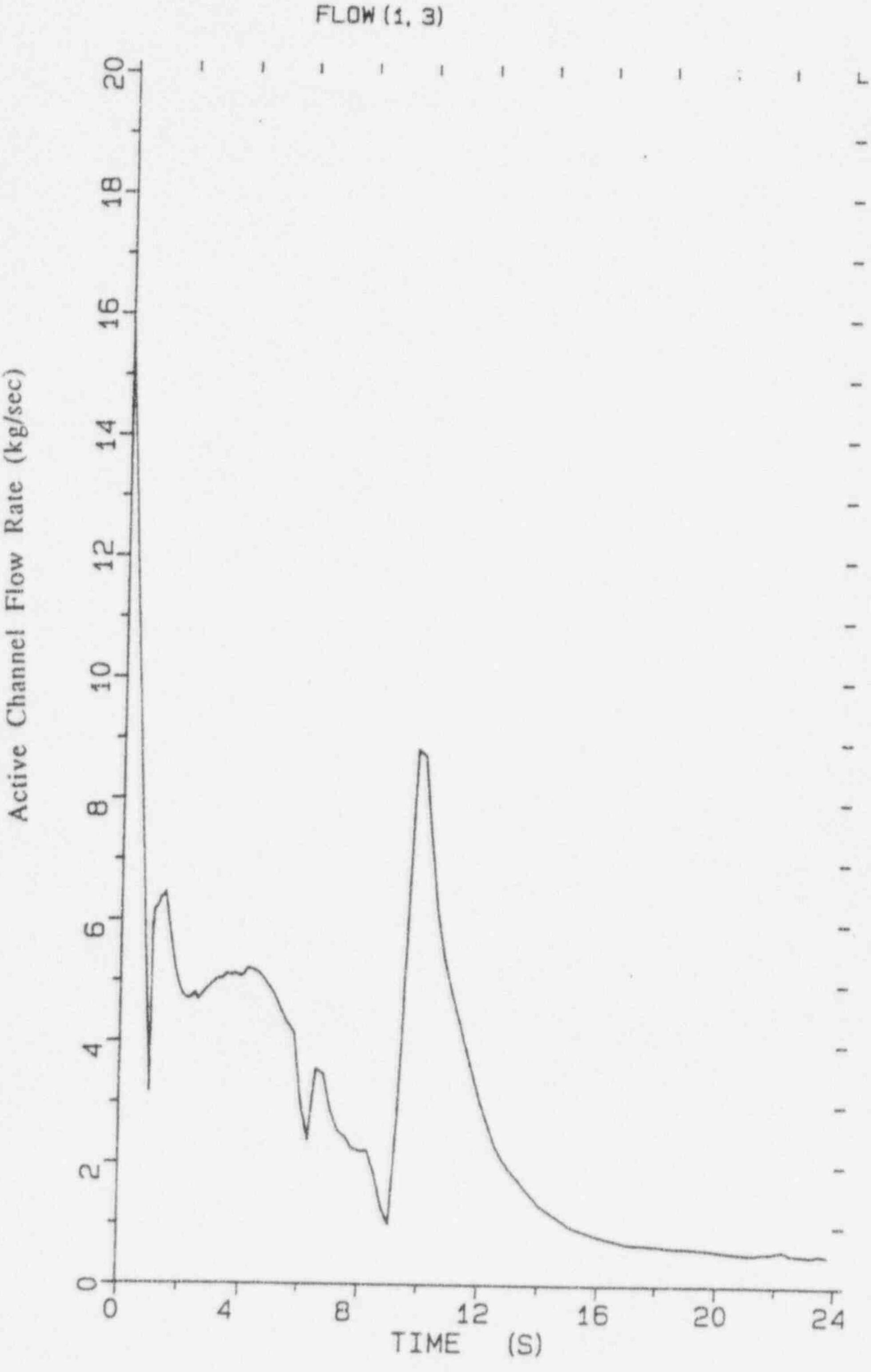

Figure 5.16 Hot Assembly Active Channel Inlet Flow

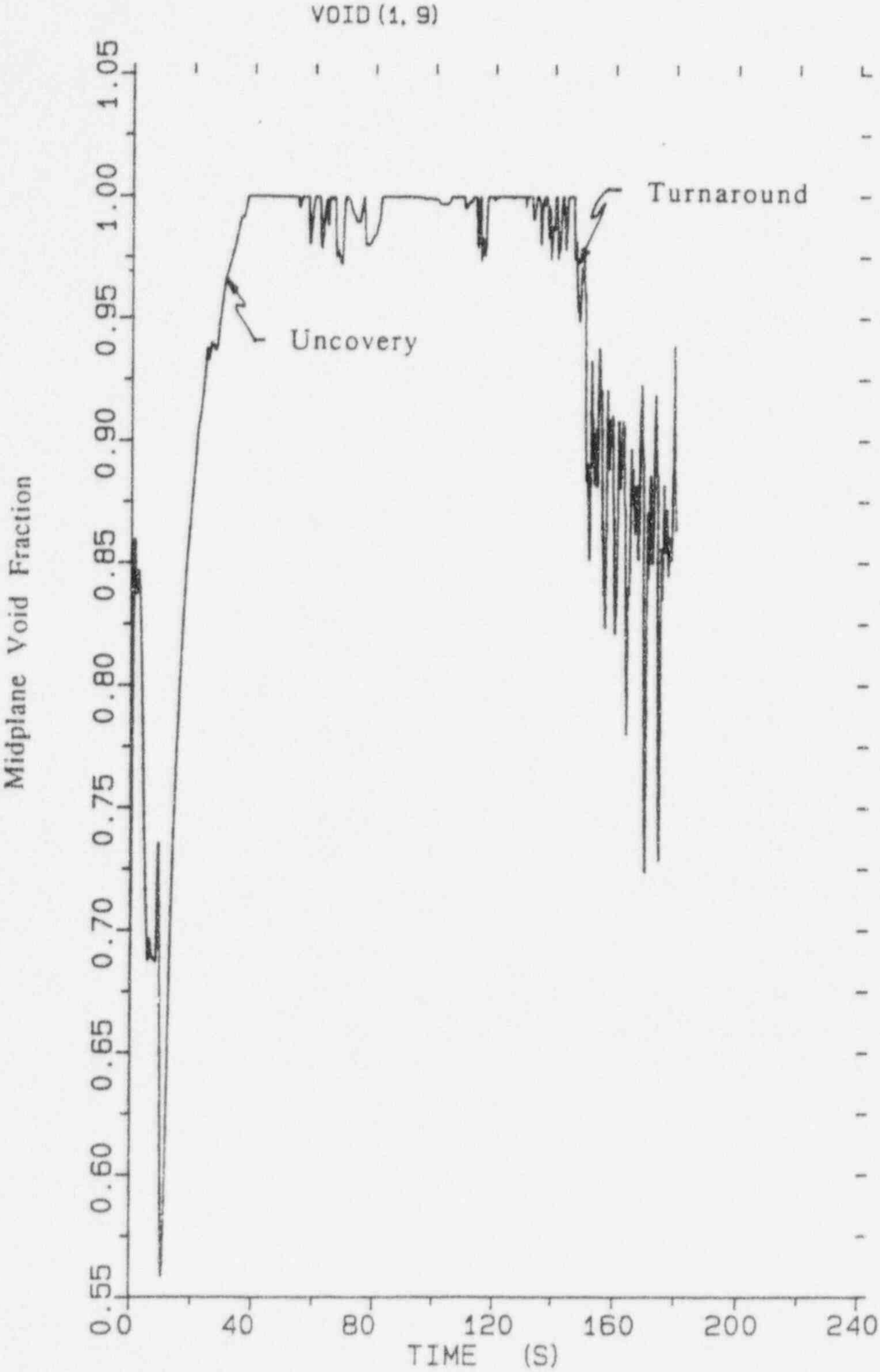

Figure 5.17 Hot Assembly Midplane Void Fraction

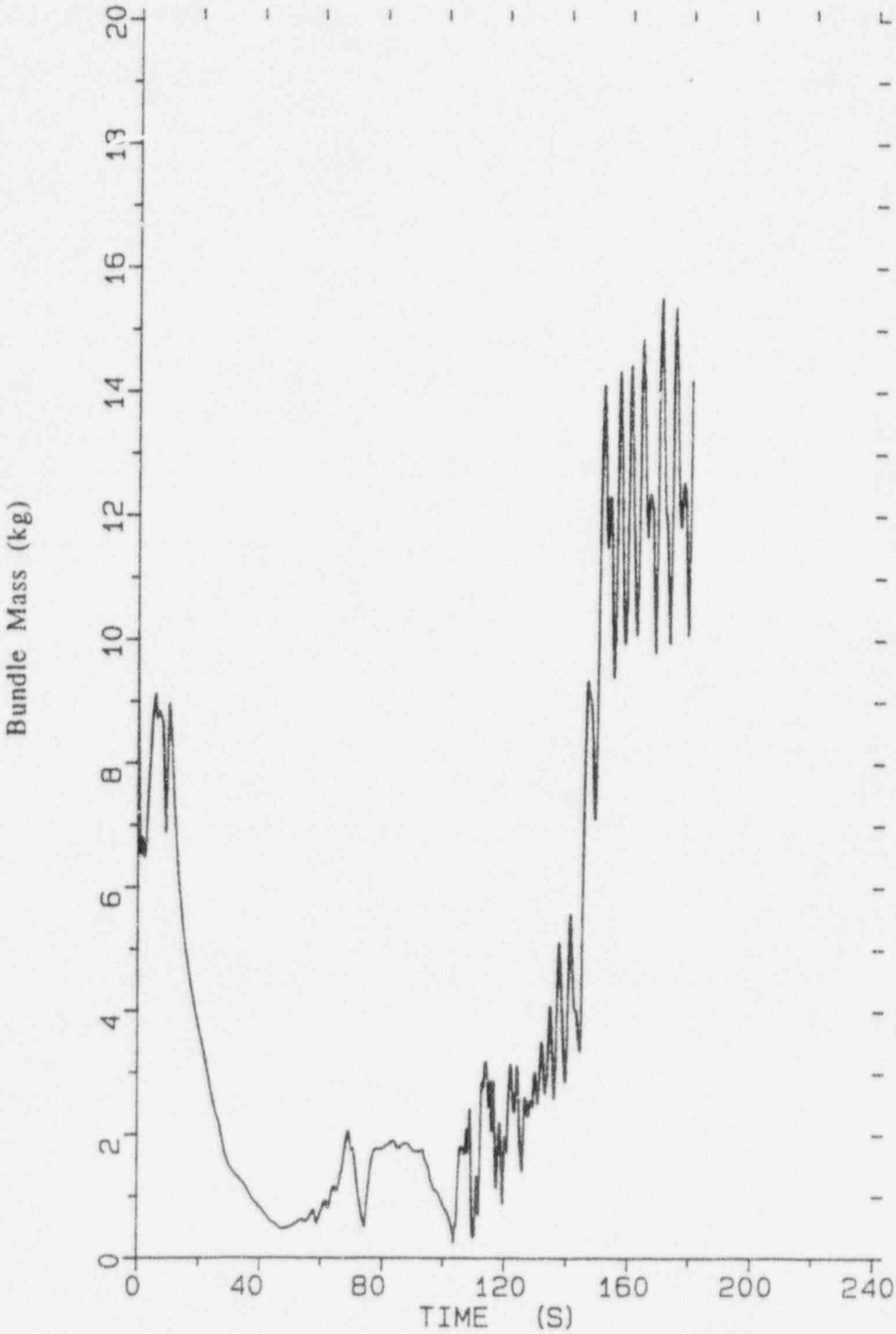

Figure 5.18 Hot Assembly Mass Inventory

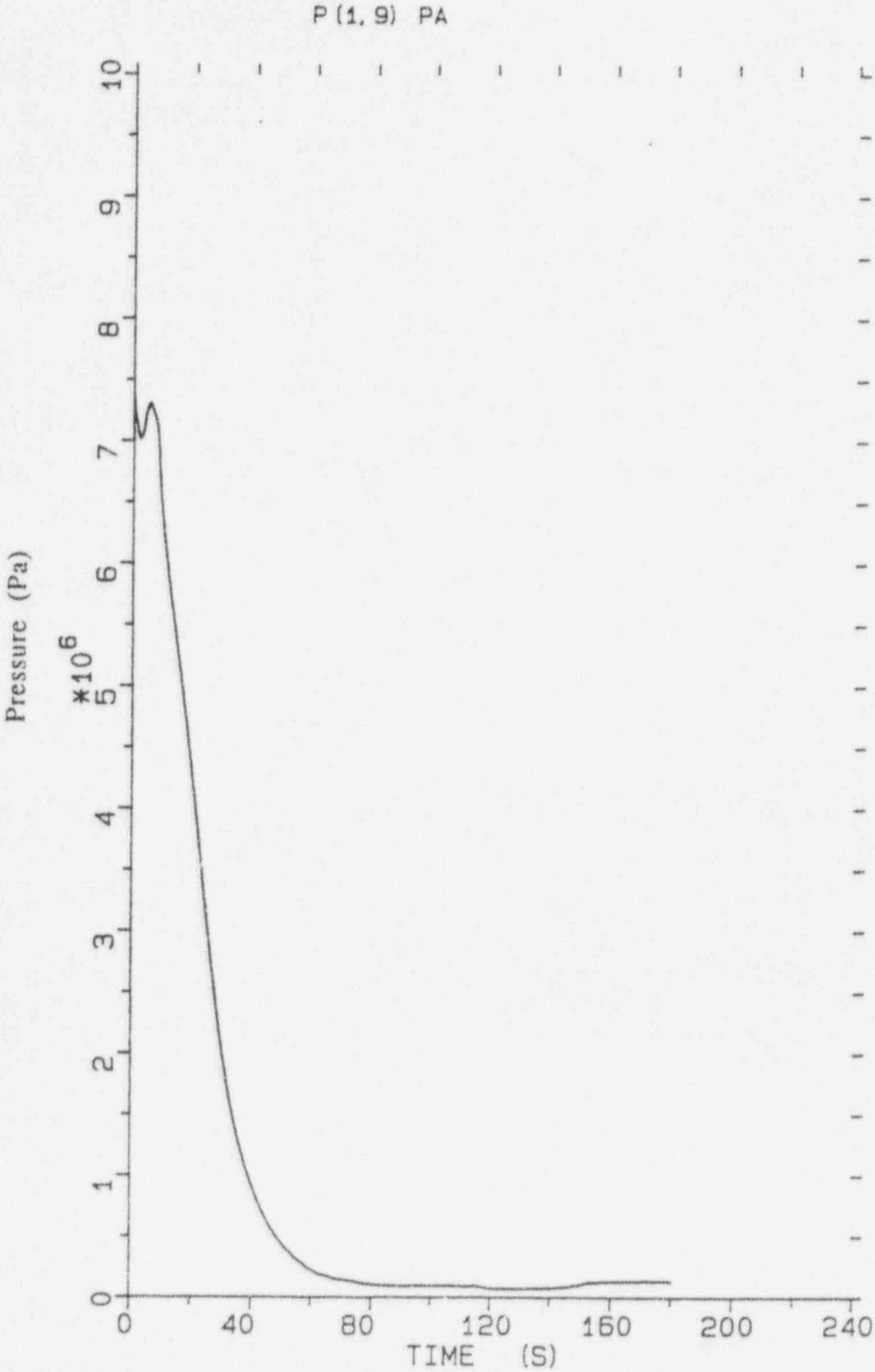

Figure 5.19 Coolant Pressure at Midplane

FIGURE 5.20 AND FIGURE 5.21

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6 NODALIZATION STUDIES

Detailed vessel. fuel assembly, and fuel rod nodalizations have been performed in Reference 1. The studies presented here are in support of nodalization changes required to model SVEA-96 fuel. The key new features are separate center box and wings flow paths. The nodalization studies presented below show that the individual flowpaths can be models as a lumped, single flowpath.

6.1 GOBLIN Model

The standard GOBLIN nodalization for the ABB BWR LOCA evaluation model is shown in Figure 3.3 and described in Section 4.1 of Reference 1. This nodalization has been maintained for the evaluation model with SVEA-96 fuel except for a few minor changes. First an additional flow path is introduced for the wings. Second, the elevation is changed for the center box and wings exit. Third, the upper plenum level tracking, which changes the upper plenum node relative volumes, was deactivated. The resulting GOBLIN nodalization for SVEA-96 fuel is shown in Figure 5.3.

Table 6.1 summarizes the noding sensitivities performed to confirm the reference nodalization.

6.1.1 Explicit Center Box and Wings

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6.1.2 Upper Plenum Level Tracking

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6.2 DRAGON Model

The standard DRAGON noding for the ABB BWR LOCA evaluation model is shown in Figure 3.14 of Reference 1. This nodalization has been maintained for the evaluation of SVEA-96 fuel with the same minor changes that are discussed above for the GOBLIN model.

The transient fluid conditions (pressure and enthalpy) for the DRAGON boundary nodes are supplied by GOBLIN. Relative power versus time is also taken from the GOBLIN run. DRAGON then calculates the thermal and hydraulic conditions in the fuel assembly throughout the transient.

Normally DRAGON is used to determine the hot assembly behavior throughout the LOCA transient. For the core nodalization study, an average power assembly has been simulated. [Proprietary Information Deleted]

Figures 6.4 through 6.8 show compa. sons of the DRAGON and GOBLIN transient results for the key parameters.

[Proprietary Information Deleted]

6.3 CHACHA-3C Model

6.3.1 Rod Noding Sensitivity

The standard CHACHA-3C fuel rod noding for the ABB BWR LOCA evaluation model [Proprietary Information Deleted] The sensitivity of the calculated peak cladding temperature to fuel rod noding has been evaluated and documented in Reference 1, Section 4.3.1. The previous sensitivities showed a negligible impact. This conclusion is not effected by the change to a smaller fuel rod design.

6.3.2 Channel Noding Sensitivity

[Proprietary Information Deleted]

TABLE 6.1

GOBLIN SENSITIVITY CASES

Case	A	B	C
Upper Plenum Level Tracking	OFF	OFF	ON
Center Box and Wings	LUMPED	EXPLICIT	EXPLICIT
Nodalization Figure No.	5.3	6.1	6.1

TABLE 6.2

GOBLIN SENSITIVITY STUDY RESULTS

Case	A	B	C
Midplane Dryout (sec)	#	#	#
HPCS Actuation (sec)	#	#	#
Initiation of Spray Cooling (sec)	#	#	#
LPCI Actuation (sec)	#	#	#
Guide Tubes Full (sec)	#	#	#
Midplane Reflood (sec)	#	#	#
Bypass Full (sec)	#	#	#

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TABLE 6.3

CHACHA CHANNEL NODALIZATION SENSITIVITY

Case	Reference	Thick	Thin
Channel Thickness (cm)	#	#	#
Peak Cladding Temperature (C)	#	#	#

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FIGURE 6.1 THROUGH FIGURE 6.8

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7 ASSESSMENT OF CODE MODELS AND PLANT PARAMETERS

This section addresses the applicability of several key code models to the SVEA-96 fuel design and the effect of key plant parameters on the evaluation of SVEA-96 fuel. The effected GOBLIN/DRAGON code models are countercurrent flow limitation and convective spray heat transfer coefficients. The key plant parameter effected by SVEA-96 fuel is the nuclear peaking factors.

7.1 Countercurrent Flow Limitation

The ABB BWR LOCA evaluation model has a comprehensive Countercurrent Flow Limitation (CCFL) model for determining the rate of liquid drainage into the SVEA-96 fuel assembly. The correlation is documented in Reference 2, Section 3.3. ABB originally developed the CCFL correlation for 8x8 fuel assemblies. Since its original development, the correlation has been generalized and validated for many geometries. Further, the correlation, with its general geometric dependence, has been confirmed valid for QUAD+ fuel through comparisons with experimental data (see response to Question 8 in Reference 2). The SVEA-96 geometry basically is the same as the SVEA-64 and QUAD+ geometry. Differences in area of the flow restrictions are accounted for in the CCFL correlation. In the LOCA evaluation model the CCFL correlation with the appropriate geometric parameters for SVEA-96 fuel, will be used.

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7.2 Convective Heat Transfer During Spray Cooling

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Background

The heat transfer during spray cooling consists of convective and radiative cooling. 10 CFR 50 Appendix K states allowable values for convective heat transfer coefficients during spray cooling.

7x7 Fuel Convective Spray HTCs

Heat transfer coefficient W/m^2-K (Btu/hr-ft-F)	Inner Rods	Side Rods	Corner Rods	Channel
Appendix K (isotropic radiation)	8.5 (1.5)	19.9 (3.5)	17.0 (3.0)	28.4 (5.0)

These values are based on experimental data for 7x7 fuel (BWR-FLECHT test program) and they are valid together with a specific radiation model used to derive the convective HTCs. This radiation model has isotropic reflection of the incident radiative flux which leads to an overprediction of energy transport from the center of the fuel bundle towards the canister. This overprediction is compensated by low evaluated values of the convective HTCs for the central fuel rods.

[Proprietary Information Deleted]

7.3 Power Peaking Factor

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Changes in bundle peaking shows no significant change in the trends of the hot assembly and rod heat up response.

TABLE 7.1

GOBLIN CCFL SENSITIVITY

Case	A	D
CCFL model relative liquid flow (UTP and grid)	100%	70%
Midplane Dryout (sec)	#	#
HPCS Actuation (sec)	#	#
Initiation of Spray Cooling (sec)	#	#
LPCI Actuation (sec)	#	#
Guide Tubes Full (sec)	#	#
Midplane Reflood (sec)	#	#
Bypass Full (sec)	#	#

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TABLE 7.2

CHACHA SPRAY HEAT TRANSFER SENSITIVITY

Case	Reference	80% Reduction
Spray Heat Transfer Coefficient (W/m2-C)		
Inner	#	#
Side	#	#
Corner	#	#
Peak Cladding Temperature (°C (°F),	#	#

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TABLE 7.3

BUNDLE PEAKING FACTOR SENSITIVITY

Case	Reference	Higher	Maximum
Bundle Peaking Factor	#	#	#
MAPLHGR (kW/ft)	#	#	#
First Dryout (sec)	#	#	#
Midplane Dryout (sec)	#	#	#
Midplane Uncovery (sec)	#	#	#
Midplane Reflood (sec)	#	#	#
Peak Cladding Temperature (°C (°F))	#	#	#
Rods Burst	#	#	#

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FIGURE 7.1

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8 TRANSITION CORES

When a utility changes to a new fuel design, the reactor can have several different fuel designs present in the core. These reload cycles are referred to as mixed or transition cores. The potential for a transition core raises the issue of the sensitivity of system response for a postulated LOCA to the core composition. In Reference 1, the LOCA system response was shown to be insignificantly altered when SVEA-64/QUAD+ watercross fuel is introduced into a core of open lattice 8x8R fuel. It follows that the introduction of SVEA-96 fuel into a core composed of open lattice fuel will not alter the calculated system response more than observed in the calculations in Reference 1. This is confirmed by comparing the SVEA-96 reference transient system response presented in Section 5 to the results in Reference 1. The transient response agrees very well with that for 8x8R and SVEA-64/QUAD+ fuels reported in Reference 1. The timing of key events are summarized in Table 8.1. Figure 8.1 shows a typical comparison. Specifically, the bundle inlet flows for each fuel type are shown. The full core and mixed core analyses presented here and in Reference 1 all show very minor changes in timing of key phenomena. Hence the presence of SVEA-96 fuel in a mixed core will not adversely impact the calculated fuel type specific LOCA limits.

TABLE 8.1

LOCA SYSTEM RESPONSE FOR FULL CORE OF FUEL TYPE

Case	SVEA-96	8x8R	SVEA-64 / QUAD+
Jet Pump Uncovery	5.9	6.8	5.9
Jet Pump Flashing	6.3	6.8	6.4
Lower Plenum Flashing	9.1	9.0	9.7
Avg. Channel Midplane Dryout	22	23	22.4
HPCS Initiation	27	27	27
Initiation of Spray Cooling	48	46	48
LPCI Initiation	53	53	53
Avg. Channel Midplane Reflood	149	149	142

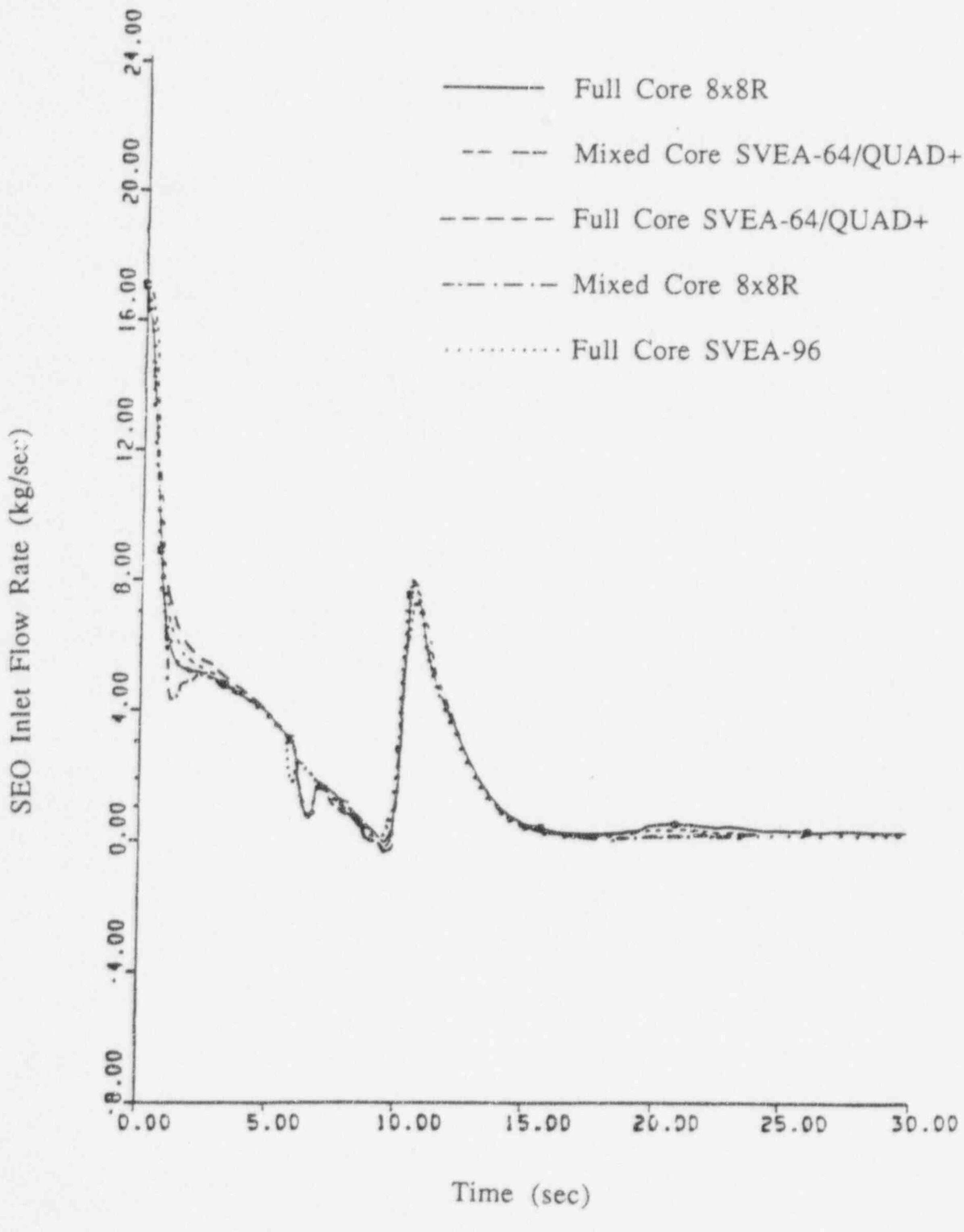

Figure 8.1 Side Entry Orifice Flow per Assembly for Each Fuel Type

9 SUMMARY AND CONCLUSIONS

The GOBLIN system of computer codes is used by ABB to evaluate Emergency Core Cooling system (ECCS) performance in boiling water reactors (BWR). The codes and methodology have been generally approved by the U. S. NRC and applications for a BWR/5,6 with SVEA-64/QUAD+ fuel provided in the original submittal (References 1 and 2). This report presented application of the ABB ECCS methodology for the SVEA-96 fuel design in a BWR/5,6 plant design.

The report conclusions are:

1. The nodalization used for the previously presented SVEA-64/QUAD+ fuel design is applicable to the SVEA-96 fuel design with minor flow path changes consistent with the change in fuel design.

2. The overall LOCA transient response does not change with the introduction of SVEA-96 fuel. The SVEA-96 fuel design, however, yields lower peak cladding temperatures than 64 rod array designs due to the lower rod linear heat generation rate.

3. The LOCA evaluation model will use a NRC approved critical heat flux correlation for SVEA-96. The correlation documented in Reference 7, was used in the evaluations presented here and is approved by the U.S. NRC.

4. The convective spray heat transfer coefficients used for SVEA-96 fuel are consistent with the heat transfer specified in 10 CFR 50 Appendix K. They are derived based on experimentally confirmed methods. Studies show less sensitivity to convective spray heat transfer than previous 8x8 fuel designs owing to the lower linear heat generation rate and improved radiative cooling.

5. The full core and mixed core LOCA system responses demonstrate that the presence of SVEA-96 fuel in a transition core will not adversely impact the other fuel type specific LOCA analyses.

10 REFERENCES

1. "Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Sensitivity," ABB RPB 90-94-P-A (proprietary), October 1991.

2. "Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Description and Qualification," ABB RPB 90-93-P-A (proprietary), October 1991.

3. "Westinghouse Reference Safety Report for BWR Fuel," WCAP-11500 (proprietary), August 1987.

4. "Mechanical Design Report for SVEA-96 Fuel," ABB Report CENPD-287-P-A (proprietary), CENPD-287-NP-A (nonproprietary), July 1996.

5. Code of Federal Regulations 10 Part 50, Federal Register, 1992.

6. J. S. Chiou and L. E. Hochreiter, "COBRA/TF Analysis of SVEA Spray Cooling Experiments," 1989 National Heat Transfer Conference, HTD-Vol. 106, page 69-80.

7. "SVEA-96 Critical Power Experiments on a Full Scale 24-Rod Sub-bundle," ABB Atom Report UR 89-210 (proprietary), November, 1989.

APPENDIX A: RESPONSES TO REQUEST FOR ADDITIONAL INFORMATION

A.1 Introduction

This appendix contains responses to the NRC Request for Additional Information regarding Reference A1 which was transmitted to ABB by the NRC in Reference A2.

The calculations presented in this document use the NRC approved LOCA evaluation methods described in References A4 and A5, which have been designated "USA1".

A.2 Questions and Responses

NRC Question A1

ABB/CE should define and justify" hydraulic compatibility" between SVEA-64 and -96 fuels.

ABB Response to Question A1

Reload fuel types are hydraulically compatible with the resident fuel in the core when:

(1) The pressure drop characteristics of the reload fuel types are similar enough to the resident fuel characteristics to assure that the thermal and mechanical performance of all of the assemblies in the mixed core are within acceptable limits, and

(2) Active flow and bypass flow fractions of the reload fuel are within the design range for the plant for operating conditions which span the power/flow domain.

The manner of demonstrating hydraulic compatibility is described in Section 5.3.3 of CENPD-300-P-A (Reference A3). This method will be used for each reload as a part of the core design effort.

Question A1 specifically requested that hydraulic compatibility of SVEA-64 and SVEA-96 fuels be justified. There are no current plans to load batches of SVEA-64 and SVEA-96 into the same core in the U.S. The demonstration of hydraulic compatibility is a process which involves the whole core, as well as the individual fuel bundles. Should SVEA-64 and SVEA-96 be loaded into the same core, the methods described in Section 5.3.3 of CENPD-300-P-A would be used to demonstrate hydraulic compatibility.

The core designs of SVEA-64 and SVEA-96 fuel used in the sample LOCA calculations presented in Reference A3 and A1 are similar designs as shown in the table below.

Fuel Type	Core Pressure Drop at Rated Conditions	Bypass Flow Fraction at Rated Conditions
SVEA-64	[#	#]
SVEA-96	[#	#]

\# Proprietary Information Deleted

Note that these characteristics can be modified by changing bypass flow hole sizes and lower tie plate flow hole sizes. These adjustments may be necessary to achieve hydraulic compatibility with different types of resident fuel on a plant specific basis.

NRC Question A2

The code qualification was performed with QUAD+/SVEA-64 fuel in RPB 90-94-P-A and RPB 90-93-P-A. Since the extension is sought with SVEA-96 fuel, ABB/CE should justify that other model qualifications and the experimental data used in the code qualification for its ECCS methodology remain applicable to SVEA-96.

ABB Response to Question A2

Licensing Topical Reports RPB 90-94-P-A and RPB 90-93-P-A (Reference A4 and A5) describe a significant amount of code qualification work. Table A2-1 summarizes the qualification cases and their applicability to SVEA-96 fuel. Much of this qualification (e.g., TLTA integral tests and jet pump model against INEL 1/6 scale data) is independent of the fuel type. Where there is a fuel type dependence, a reference is given to the location of the performed qualification specifically for SVEA-96 fuel. The applicable general qualification is also referenced.

NRC Question A3

ABB/CE is required by the SER on UR 89-210 that ABB/CE demonstrate that the use of the XL-S96 CPR correlation with GOBLIN/DRAGON produces bounding or conservative predictions of CPR by presenting analysis specifically to address adequacy of implementation.

ABB Response to Question A3

Implementation of the XL-S96 boiling length critical power correlation in GOBLIN/DRAGON is described in Section 4.1 of CENPD-293-P-A (Reference A7). ABB has certified in Response B3 on CENPD-293-P-A that the formulation of the XL-S96 correlation is identical to that reviewed and approved in UR-89-210-P-A. Adequacy of implementation is addressed in Section 7.1 of CENPD-293-P-A.

The calculations presented in this report used the "USA1" licensing methodology and the use the fuel specific CPR correlation for the SVEA-96 fuel design. The sample calculations and sensitivity studies presented in this report are independent of the specific CPR correlation used. [Proprietary Information Deleted]

NRC Question A4

The vendor is relying upon conclusions reached with SVEA-64 to conclude that the same conclusion would be reached for SVEA-96 with the ECCS methodology. ABB/CE should provide FULL range of calculational graphic results and compare between analyses for SVEA-64 and SVEA-96 (p.15).

ABB Response to Question A4

The full range of calculational results for the hot assembly response, discussed in Section 5.3, are shown for a sample case with SVEA-96 fuel in Figures 5.16 through 5.21 of this report. Similar calculational results were presented for the QUAD+/SVEA-64 fuel design in Figures 3.16 through 3.20 and Figure 3.22 of RPB-90-94-P-A (Reference A4). Figures A4-1 through A4-6 present a direct comparison of the hot assembly response for SVEA-96 and SVEA-64 fuel. This direct comparison shows the small differences between the two calculated hot channel responses. The small differences in results are attributed to differences in flow geometry, fuel rod geometry, nodalization, and simulation assumptions (all discussed in detail in this report). It is apparent that the differences in responses as a result of the change in fuel design and modeling assumptions are minimal.

NRC Question A5

The original topical report concluded that level tracking was important. In this topical report ABB/CE proposes to deactivate the level tracking in the upper plenum in an effort to reduce computer time. ABB/CE should demonstrate that conservatism is not compromised by eliminating this option. Thorough discussion of its impact upon PCTs should be included in the response.

ABB Response to Question A5

In the original Evaluation Methodology (Reference A4) the level tracking was used in three regions - upper plenum, lower plenum, and downcomer region. This Licensing Topical Report demonstrates that accurate results are obtainable without activation of the upper plenum level tracking model. ABB will have the option to perform LOCA analysis with or without the upper plenum two-phase level explicitly modeled.

The GOBLIN level tracking model is described in Section 3.3.2 of RPB 90-93-P-A (Reference A5). This model is used to determine energy partition when the two-phase level is near the elevation of a flow path, specifically influencing the fraction of liquid and vapor entering the flowpath. In the level tracking model, the two-phase level position is a primary variable, solved for in the solution matrix, replacing the mass flow rate. The model has been generally used in LOCA analysis for the upper plenum, lower plenum, and downcomer region. These regions typically have coarse nodalization, changing two-phase levels, and horizontal flow junctions.

Experience with the GOBLIN code has shown that the upper plenum level tracking provides an insignificant contribution to the simulation accuracy. Figure 3.10 of Reference A5 shows an example response of the upper plenum level during a LOCA event. The three static upper plenum nodes adequately simulate level changes that occur during the event. Hence, in LOCA analysis, it is sufficient to perform calculations without explicitly tracking the upper plenum level.

To further demonstrate that the effects of using the upper plenum level tracking model are minimal, the LOCA reactor system response described in Section 5.2 of this report, was repeated using upper plenum two-phase level tracking as described in Section 6.1.2 of this report. Figures A5-1 through A5-5 show graphically the comparison results with the upper plenum level tracking turned on and off. It is apparent that there is very little difference in responses. The peak cladding temperature for both cases is shown in Figure A5-5. It can be seen that the PCT is unchanged when the upper plenum level is not explicitly modeled.

NRC Question A6

In the SVEA-64 design, the cruciform structure has a uniform geometry, while in the SVEA-96, the wings have considerably smaller flow cross section. In the core nodalization, ABB/CE proposes modeling the central box and wings as a single channel instead of separate channels. ABB/CE should justify treating the new cruciform as a single channel; in particular, explain how the smaller openings can be lumped with the large opening for two-phase modeling and reflood. The explanation should be quantitative and accompanied by graphic results which include pressure, flow rate, void fraction, relative velocities of two phases and fuel temperature profiles.

ABB Response to Question A6

Cross sections for SVEA-64 and SVEA-96 fuel assemblies are shown schematically in Figures 3.1 and 3.3 of this report. SVEA-64/QUAD+ has a single water channel with the four wings hydraulically coupled through the center of the watercross. SVEA-96 has four hydraulically independent wings and a central water box. [Proprietary Information Deleted]

In LOCA analysis, parallel channels having similar response characteristics are typically combined. For example, in modeling SVEA-96 fuel the four wings are identical, and hence are combined both for the vessel system response and hot channel response calculations. ABB will maintain the option to also combine the center water box and water wings in the LOCA analysis. Combining the center box with the water wings assumes that the flow response of the combined channel is not significantly different than the sum of the individual channel responses.

The validity of this assumption was demonstrated in Section 6.1.1 of this report where the sample LOCA system response calculation was run with the watercross channels explicitly represented and key results compared to the combined simulation. Figures A6-1 through A6-4 show additional comparison results of the GOBLIN system response with and without explicit modeling of the water wings. The pressure, vessel mass inventory, core mass inventory, and core pressure drop are very similar.

Figures A6-5 through A6-11 show detailed results of a hot channel response with and without explicit modeling of the water wings. Figures A6-5 through A6-8 show the inlet flow rates of the fuel assembly, center box, water wings, and total watercross (center box plus water wings). Figure A6-9 shows the channel mass inventory and Figures A6-10 and A6-11 show the void fraction at the midplane for the active channel and watercross components. [Proprietary Information Deleted] The results of this delay in midplane dryout is seen in a lower final calculated peak cladding temperature for the case with the explicit center box and wings (see Figure A6-12). These additional hot channel calculations results further substantiate the assumption that the center box and water wings channels have similar response characteristics. Lumping the watercross channels in the system response produces a very similar system response. Furthermore, lumping the watercross channels in the hot channel response also produces very similar and slightly conservative results.

<u>NRC Question A7</u>

ABB/CE cannot apply to SVEA-96 the previous validation of CCFL correlation in GOBLIN/DRAGON for an 8x8 configuration due to geometric differences. Therefore, ABB should demonstrate the applicability of the CCFL correlation specifically to SVEA-96 fuel design in terms of reflood behavior (both from the top and the bottom of the core), including explanation and justification of values selected for K_l and K_u for SVEA-96.

<u>ABB Response to Question A7</u>

The countercurrent flow limitation (CCFL) model used in GOBLIN/DRAGON is a form of the Wallis (Reference A8) correlation which is widely used to predict the limitation on the downward flow of water for a given steam upflow. The model is described in Section 3.3 of RPB 90-93-P-A (Reference A5). There are two correlating parameters K_1 and K_u in the CCFL model. For a wide range of flow geometries,

[Proprietary Information Deleted] (A7-1)

has been shown to fit the data well. The parameter K_u has both a geometry and a void fraction dependence. Two geometric parameters, the hydraulic diameter, D_h and the characteristic length D_L are used in the calculation of K_u, which is determined as a function of void fraction, α, as follows:

[Proprietary Information Deleted]

The above correlation is based upon extensive round tube and world data for other geometries (Reference A8 through A12 and Response to Question 8 of Reference A5). In the GOBLIN code it is an integral part of the drift flux formulation and evaluated at all flow paths. The correlation defines the upper limit of relative velocity between phases under countercurrent flow conditions. The correlation as implemented in GOBLIN has been successful in predicting the wide range of geometries including those present in the GOBLIN qualification test matrix (i.e., TLTA and FIX-II). Comparisons have also been made to other correlations applicable to BWRs available in the literature (see Section 6.1.3 of Reference A5).

Furthermore, the CCFL correlation has been compared to test data for the SVEA watercross fuel design and found to compare very well (see Response to Question 8 of Reference A5). Based on the proven robust characteristic of the general CCFL correlation in GOBLIN and the similarity of geometries, the correlation can predict CCFL performance for the SVEA-96 fuel design when the appropriate geometric parameters are provided.

The relative importance of CCFL on the overall LOCA response for SVEA-96 fuel was studied in Section 7.1 of this report. [Proprietary Information Deleted]

For LOCA applications where the calculated peak cladding temperature is greater than 2100 °F, the general countercurrent flow limitation (CCFL) correlation when applied to SVEA-96 fuel components will include a conservative bias that bounds the scatter in the correlation database. The conservative bias introduced to the base CCFL correlation will be such that bounding predictions are obtained for all applicable fuel assembly components data in the correlation qualification database.

NRC Question A8

A key item in this report is validation of the convective spray HT coefficients, yet the argument for determination of convective heat transfer during spray cooling is lacking substance. ABB/CE should:

a. justify the conclusion that lowering the value for the central fuel rods always compensates conservatively for the overprediction of the energy transfer from the central bundle to the canister;

b. describe in detail how the data were transformed to be consistent with the improved radiation model;

c. ABB/CE's method to determine coefficients must be supported by experimental data applicable to this fuel as was done for the other fuel designs. Justify extending data obtained using 8x8, 64 fuel rod assembly test data to SVEA-96 with very different configuration.

ABB Response to Question A8

The development and justification of convective spray heat transfer coefficients for SVEA-96 fuel is summarized in Section 7.2 of this report. Presented below is a more detailed discussion of the development of a mechanistic approach for conservatively determining fuel design specific convective spray heat transfer coefficients. The discussion includes validation of the approach against experimental measurements and the application of the approach for the SVEA-96 fuel design. Following the general discussion, items (a), (b), and (c) of the reviewer's question are specifically addressed.

Background

The total heat transfer from a fuel rod, q''_{tot}, is composed of a radiative component to other surfaces, q''_{rad}, and a surface to coolant component, q''_{co}:

$$q''_{tot} = q''_{rad} + q''_{co} \qquad \text{(A8-1)}$$

The radiative heat transfer for surface "k" is calculated by (Reference A5, Equation 4.5-25),

$$q''_{rad} = \sum_{i=1}^{N} GBF_{ki} \ (\sigma T_k^4 - \sigma T_i^4) \qquad \text{(A8-2)}$$

where σ is the Stefan-Boltzmann constant, T_k is the temperature for surface "k", "i" are the other surfaces in view of rod "k", and GBF_{ki} is the gray body factor based on the surface view factor between surface "i" and "k" and radiative conditions of the surfaces (see in Reference A5, Section 4.5 for additional details).

The surface to coolant heat transfer is calculated by (Reference A5, Equation 4.1-28),

$$q''_{co} = h_{co} (T_{surf} - T_{co})$$

where h_{co} is the heat transfer coefficient and T_{surf} and T_{co} are the rod surface and coolant temperatures, respectively. For the spray cooling h_{co} is referred to as the convective spray heat transfer coefficient.

The radiative heat transfer depends on global geometric parameters of the fuel assembly, such as the rod arrangement and location of the unheated channel surfaces.

The surface to coolant heat transfer depends on local geometric parameters of the fuel assembly, such as the subchannel geometry next to the rod and rod diameter.

Fuel assembly spray cooling tests measure the fuel rod surface temperature and total heat transfer from the rod. The convective spray heat transfer is deduced from the total heat transfer and calculation of the radiative heat transfer component. Generally, a constant spray heat transfer coefficient is used for each type of rod with a similar local subchannel geometry (e.g., side, corner and interior rods). The spray heat transfer coefficients calculated from test data are not strictly independent of the rod surface temperature. Hence, when a constant set of values are used in analysis applications the set is chosen to yield conservative results in the intended range of application.

Fuel bundle tests without spray flow (radiation only tests) have been used to qualify the radiative heat transfer models. A consistent radiative model is used in the derivation and application of the spray heat transfer coefficients.

SVEA-96 convective spray heat transfer coefficients

[Proprietary Information Deleted]

ABB Response to Question A8, Item a

[Proprietary Information Deleted]

The convective heat transfer coefficients for spray cooling specified in 10CFR50 Appendix K were based on an evaluation of the BWR FLECHT test data for 7x7 fuel. In this evaluation the convective heat flux of a rod was determined as the difference of the total heat flux and the radiative heat flux. The total heat flux was determined from the rate of change of measured temperature, the heat capacity of the rod and the measured electric power generation. The radiative heat flux was determined from the measured temperatures of all rods and the channel wall using a radiation model with isotropic reflection. [Proprietary Information Deleted]

ABB Response to Question A8, Item b

[Proprietary Information Deleted]

ABB Response to Question A8, Item c

[Proprietary Information Deleted]

NRC Question A9

Mixed core effects should be investigated further to support ABB/CE's position regarding the transition cores by presenting mixed core analysis results with transition from QUAD+/SVEA64 fuel to SVEA-96 fuel. The watercross for each fuel design should be explicitly modeled in the nodalization. Provide plots from core void fraction, pressure, flow, and flow velocities.

ABB Response to Question A9

Reload cores of mixed fuel designs are designed to be hydraulically compatible (See Response A1 of this document). Cores designed to be hydraulically compatible are generically demonstrated in Reference A5, to yield a LOCA reactor system response that is insignificantly altered relative to that of a full core of one fuel design. A full core of one fuel design is used in the LOCA evaluation for that specific fuel design. Hence, the industry accepted process of performing LOCA evaluations for a specific fuel design based on a full core of that fuel design is also valid for mixed core applications.

To further demonstrate that the discussion presented and conclusions drawn in the response to Question 5 of RPB-90-94-P-A are valid in general, the results for a full core of SVEA-96 were compared to the previous system responses in Section 8 of this report. Additional comparative results are shown in Figures A9-1 through A9-8 which correspond to Figures 5-1 through 5-8 on pages 18 through 25 of the Addendum to RPB 90-94-P-A. The core compositions in the four cases presented in Figures A9-1 through A9-8 are:

Core Description	8x8R	QUAD+	SVEA-96
Full Core 8x8R	764	–	–
Mixed Core	260	504	–
Full Core QUAD+	–	764	–
Fuel Core SVEA-96	–	–	764

For the Mixed Core case, as applicable, both QUAD+ and 8x8R channel results are shown in the figure. There are insignificant differences between the system responses of the four cores presented.

As discussed in Response 5 of RPB-90-94-P-A small differences in the responses are attributed to differences in fuel component designs. As noted in Response A1 of this document, the SVEA-96 core used as an example was not specifically designed to be hydraulically comparable with the previous example cores (i.e., QUAD+ and 8x8). Hence, in some instances in Figures A9-1 through A9-8, the SVEA-96 results deviated slightly more than those observed for the other cores configurations. However, the overall system responses are very similar.

The results presented here further substantiate the general conclusion that the core average system response is relatively independent of local differences in fuel assembly design.

A.3 References

A1. Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Sensitivity for SVEA-96 Fuel, CENPD-283-P, NRC transmittal letter ATOF-93-029, March 30, 1993.

A2. NRC Facsimile Transmissions from R. Frahm (NRC) to D. Ebeling-Koning (ABB), March 20, 1995 (original) and March 28, 1995 (revision 1).

A3. Reference Safety Report for Boiling Water Reactor Reload Fuel, ABB Report CENPD-300-P-A (proprietary), CENPD-300-NP-A (nonproprietary), July 1996.

A4 Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Sensitivity, ABB Report RPB-90-94-P-A (proprietary), RPB-90-92-NP-A (nonproprietary), October 1991.

A5. Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Description and Qualification, ABB Report RPB-90-93-P-A (proprietary), RPB-90-91-NP-A (nonproprietary), October 1991.

A6. Fuel Assembly Mechanical Design Methodology for Boiling Water Reactors, ABB Report CENPD-287-P-A (proprietary), CENPD-287-NP-A (nonproprietary), July 1996.

A7. Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Supplement 1 to Code Description and Qualification, CENPD-293-P-A (proprietary), CENPD-293-NP-A (nonproprietary), July 1996.

A8. Graham B. Wallis, One-dimensional Two-phase Flow, McGraw-Hill Book Co., 1969, p 339.

A9. K. H. Sun "Flooding Correlations for BWR Bundle Upper Tieplates and Bottom Side-Entry Orifices," Multiphase Transport: Fundamentals, Reactor Safety, Applications; Hemisphere Publishing, 1979 pg. 1615-1635.

A10 General Electric Company Analytical Models for Loss of Coolant Analysis in Accordance with 10CFR50, Appendix K, NEDO-20566, 1976.

A11 S. O. Eriksson et al., Experimental Med Motriktade Ångföden I Strilkylningskretsen, GÖTA, Studsvik, AES-15, 1977.

A12 J. A. Holmes, Description of the Drift Flux Model in the LOCA Code RELAP-UK, Conference in the Heat and Fluid Flow in Water Reactor Safety, I Mech E Manchester, 1977.

A13. J. S. Chiou and L. E. Hochreiter, COBRA/TF Analysis of SVEA Spray Cooling Experiments," 1989 National Heat Transfer Conference, HTD-Vol. 106, page 69-80.

A14. R. Pettersson, "GÖTA Data Analysis, SKI Project B 39/77. Final Report" , ABB Atom Report RCC 79-107, 1979.

TABLE A2-1

LOCA METHODS QUALIFICATION MATRIX

Code Model/ Qualification Test	Applicability	Reference General Qualification	Reference for SVEA-96 Qualification
Drift Flux	fuel type independent; uses fuel specific geometric information	Reference A5, Sect. 6.1.1	-
Level Swell	fuel type independent	Reference A5, Sect. 6.1.2	-
Countercurrent Flow Limitation	fuel type dependent; uses fuel specific geometric information	Reference A5, Sect. 6.1.3 and response to Question 8	This document response to Question A7
Fuel Bundle Pressure Drop	fuel type dependent; included in fuel design mechanical design evaluation	Reference A5, Sect. 6.1.4; Reference A3, Sect. 5.3.3	Reference A3, Sect. 5.3.3
Jet Pump	fuel type independent	Reference A5, Sect. 6.1.5	-
CHF Correlation	fuel type dependent; uses fuel specific correlation	Reference A5, Sect. 6.1.6	Reference A7, Sect. 7.1
Post-Dryout Heat Transfer	fuel type independent	Reference A5, Sect. 6.1.7	-
Reactor Power Generation Model	fuel type independent	Reference A5, Sect. 6.1.8	-

TABLE A2-1 (CONTINUED)

LOCA METHODS QUALIFICATION MATRIX

Code Model/ Qualification Test	Applicability	Reference General Qualification	Reference for SVEA-96 Qualification
Fuel Rod Conduction Model	fuel type independent; uses fuel specific geometric information	Reference A5, Sect. 6.1.9; Reference A7, Sect. 7.3	-
Cladding Strain and Rupture Model	fuel type independent; uses fuel specific geometric information	Reference A7, Sect. 7.2	-
Radiation Heat Transfer Model	fuel type independent; uses fuel specific geometric information	Reference A5, Sect. 6.1.11	-
Spray Cooling and Channel Wetting	fuel type dependent; uses fuel specific values	Reference A5, Sect. 6.1.11	Sect. 7.2 of this report
Integral System Qualification	fuel type independent; uses test fuel specific geometric information	Reference A5, Sect. 6.2 and 6.3; Reference A7, Sect. 7.4	-

FIGURE A4-1 THROUGH FIGURE A8-3

Proprietary Information Deleted

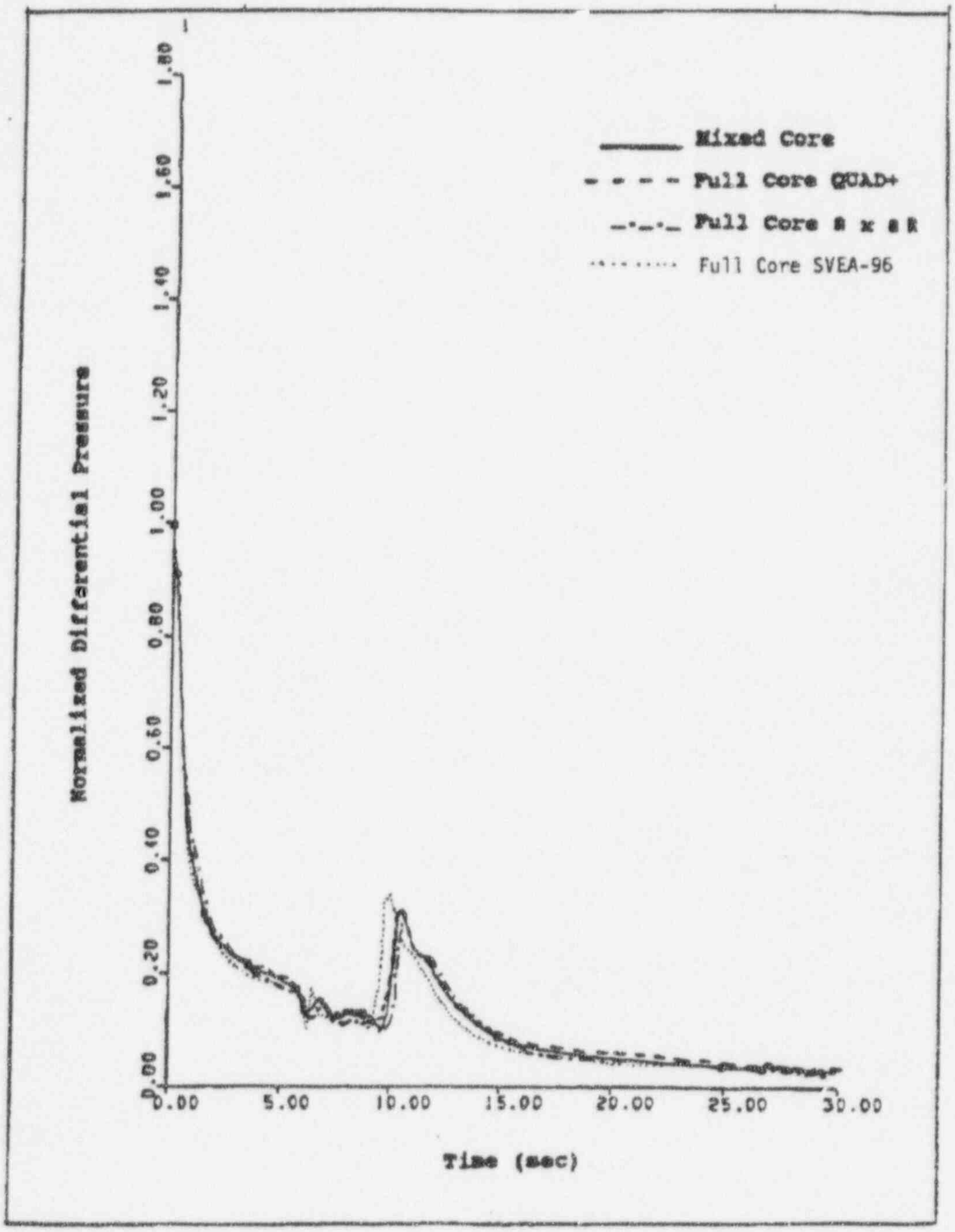

Figure A9-1 Normalized Assembly Differential Pressure versus Time

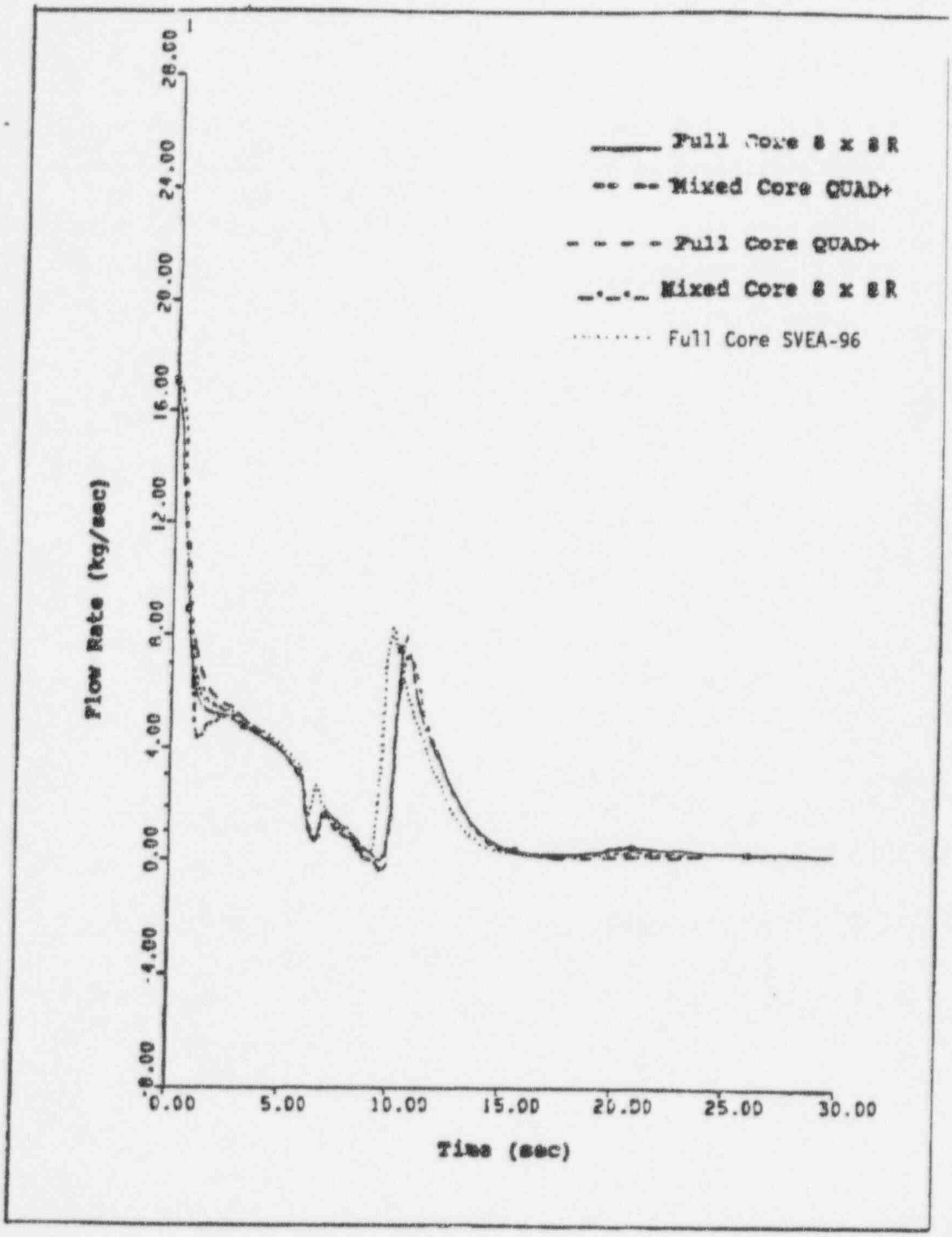

Figure A9-2 Side Entry Orifice Flow per Assembly versus Time

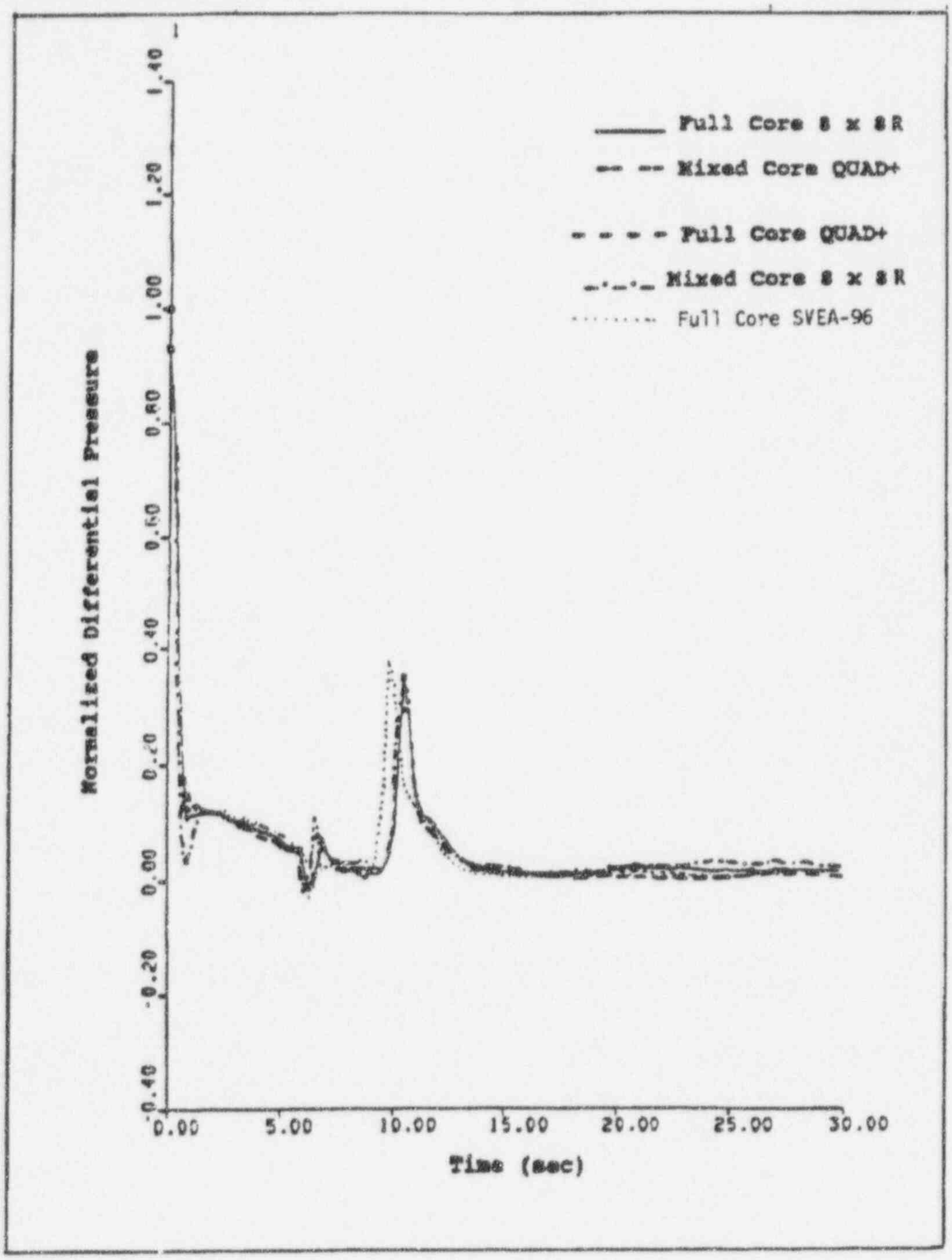

Figure A9-3 Normalized Side Entry Orifice Differential Pressure versus Time

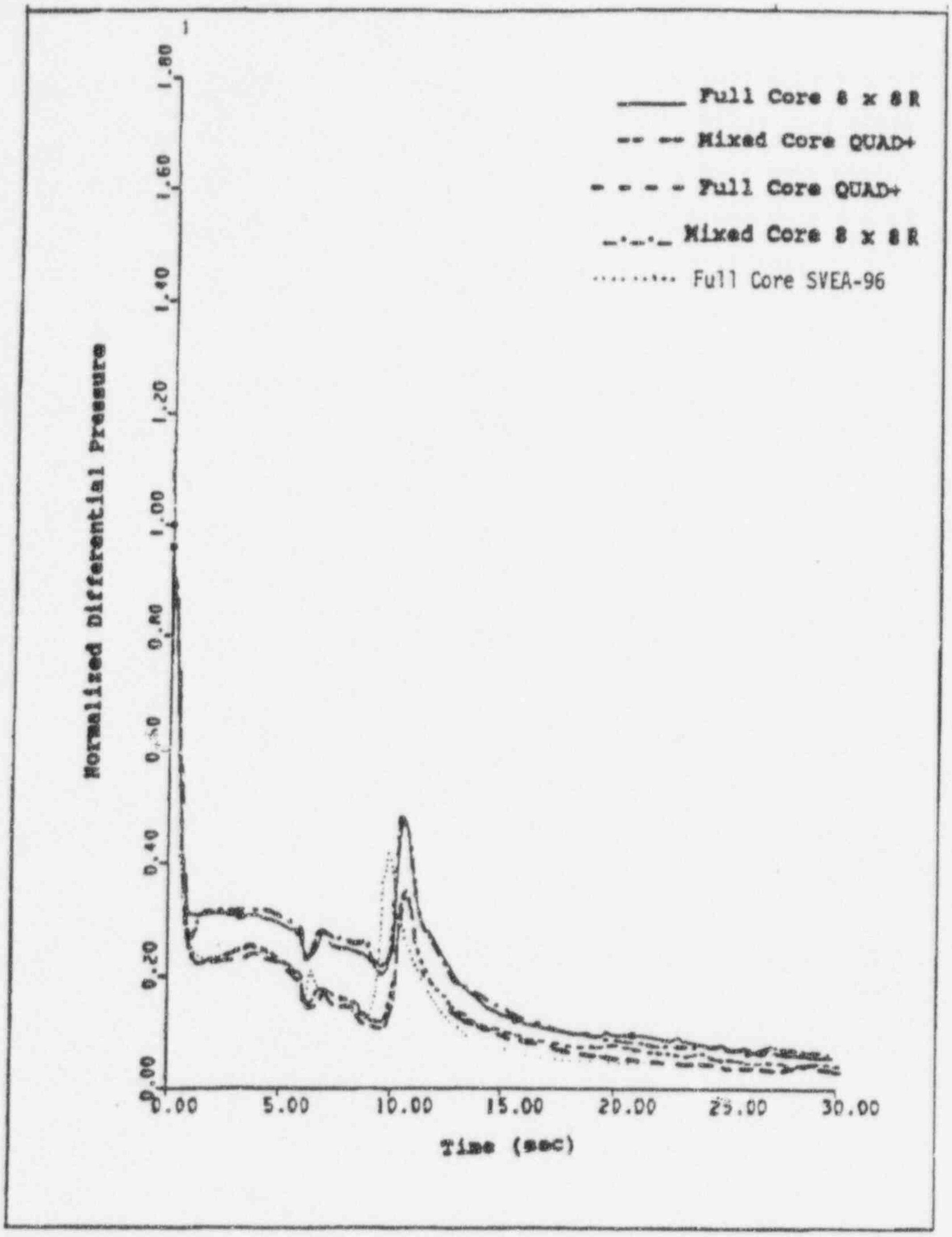

Figure A9-4 Normalized Lower Tie Plate Differential Pressure versus Time

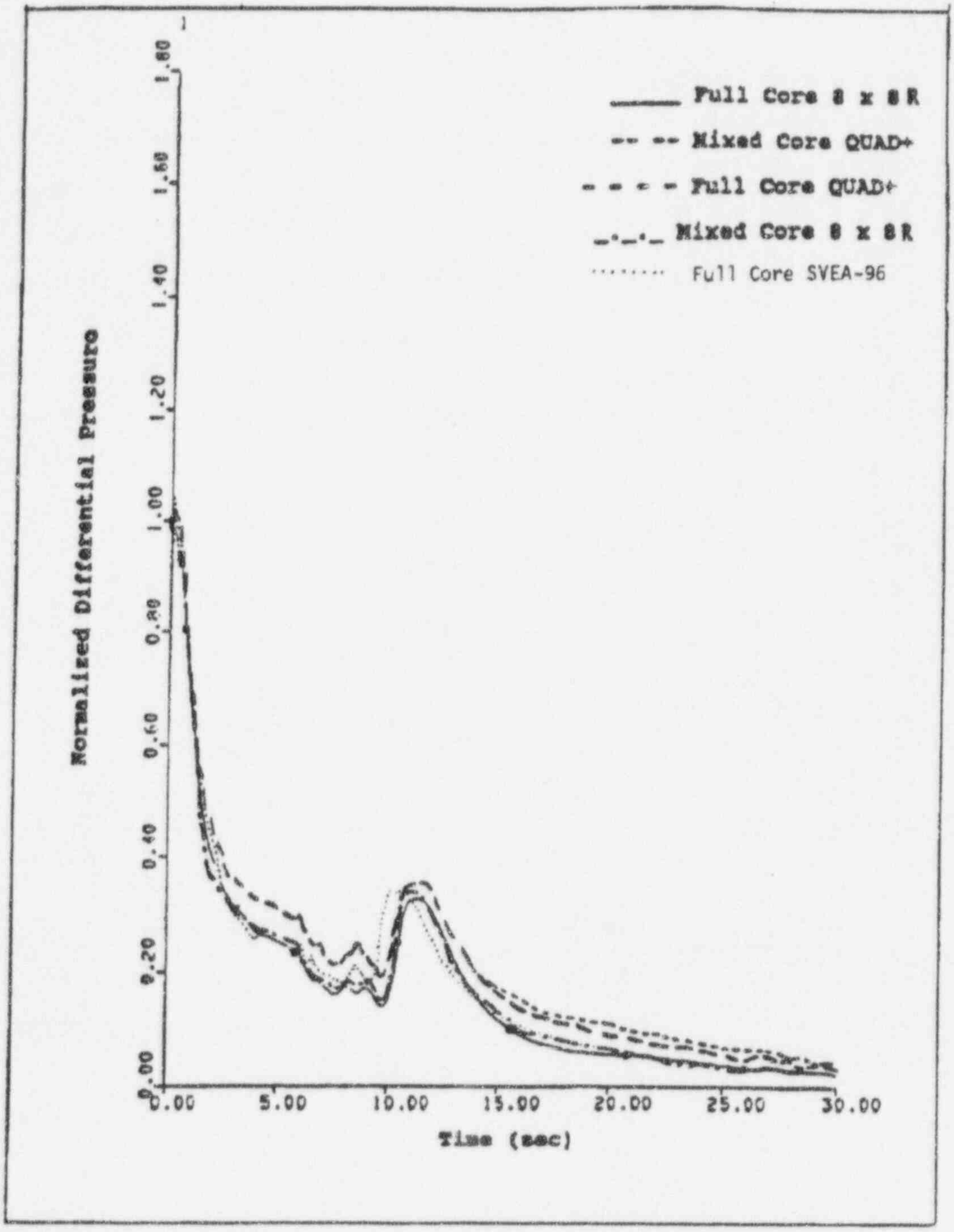

Figure A9-5 Normalized Heated Length Differential Pressure versus Time

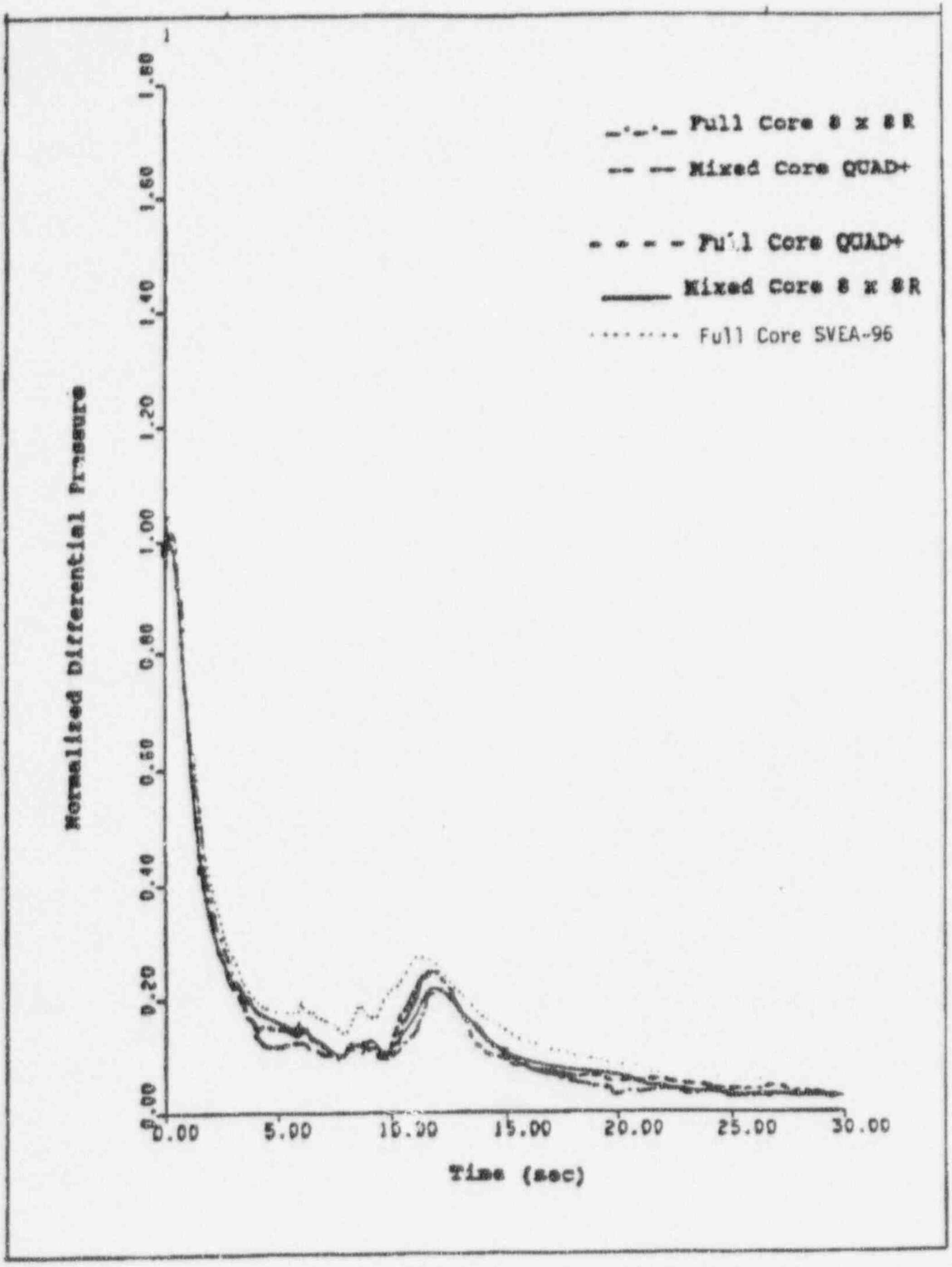

Figure A9-6 Normalized Upper Tie Plate Differential Pressure versus Time

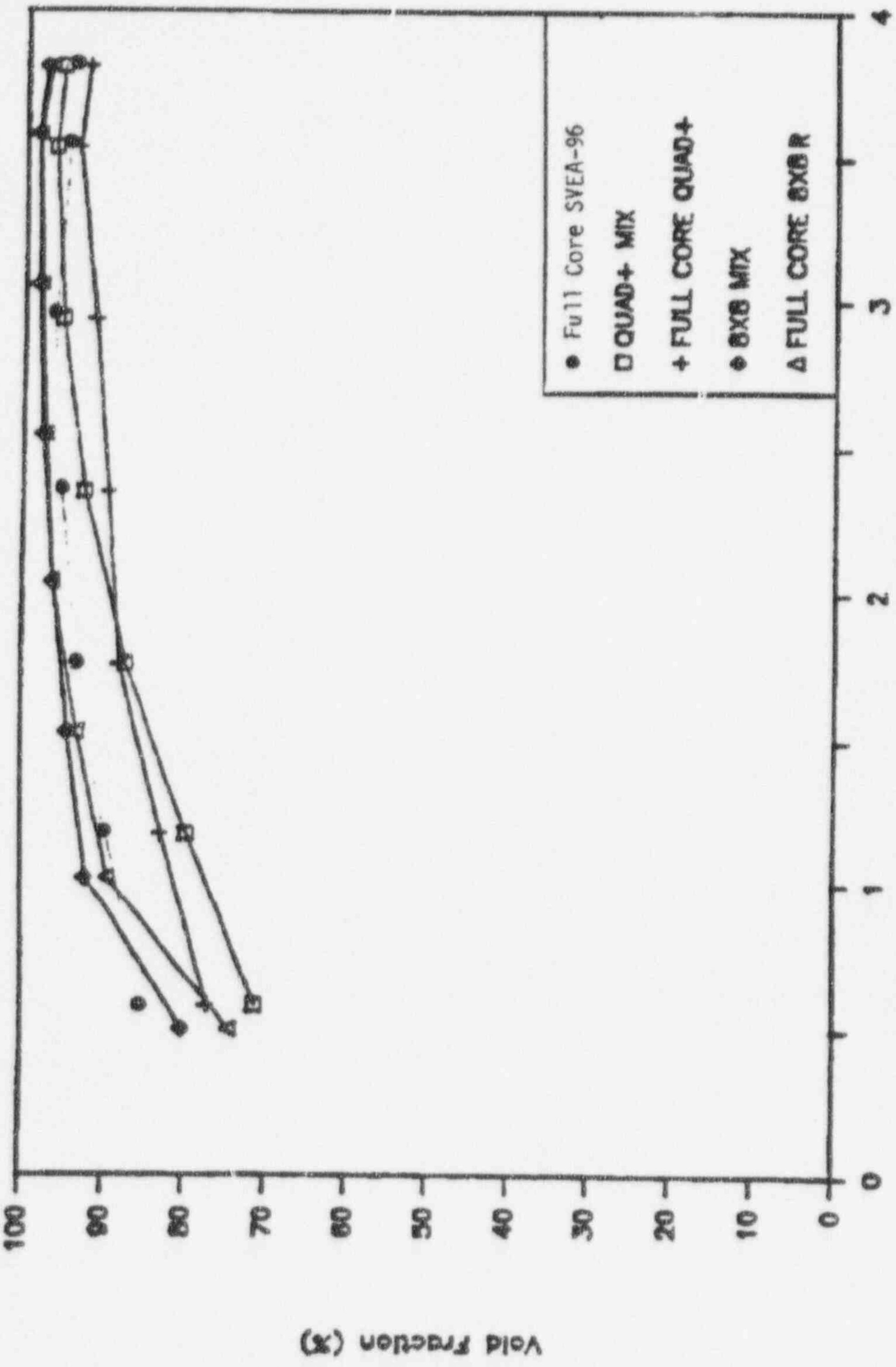

Figure A9-7 Core Void Fraction at 20 Seconds versus Core Elevation

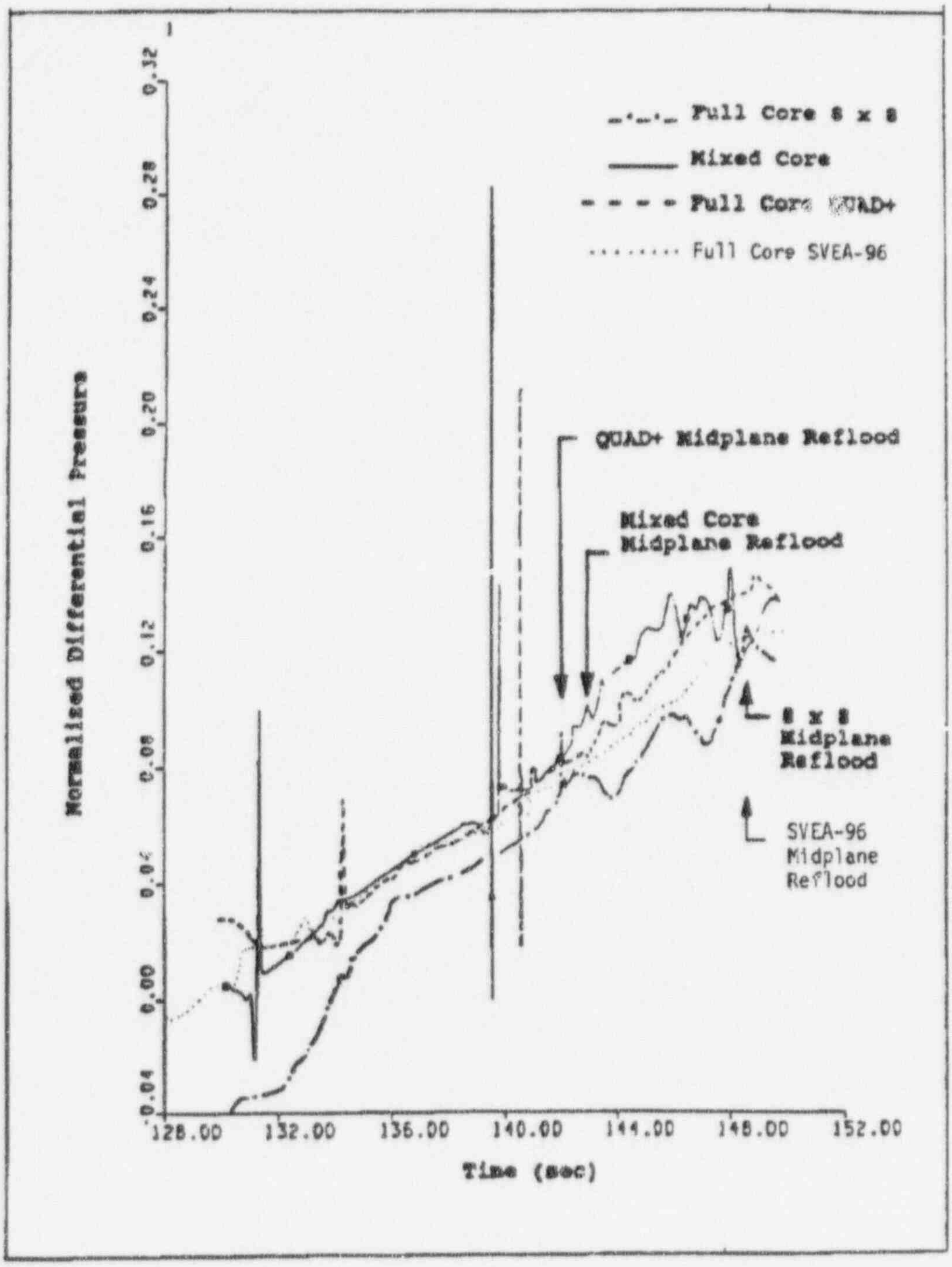

Figure A9-8 Normalized Assembly Differential Pressure versus Time

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